Dynamic factors influencing future domestic waste flows in the City of Cape Town

by

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Declaration

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Abstract

The production of waste in cities is one of the largest challenges to urban sustainability. Waste generation continue to grow with increasing population. Waste management has become challenging for urban and city managers. This study therefore explored the dynamic factors influencing future domestic waste flows in the City of Cape Town. This was achieved by first undertaking a literature analysis to examine the drivers of waste flows and exploration of municipal waste management as a complex system. A qualitative system dynamics approach mainly using causal loop diagrams was then utilised, and three feedback loops essential for managing waste were identified, namely: public health feedback loop, waste resource management feedback loop, and environmental protection feedback loop. The public health feedback loop revealed that residents' behavioural problems in combatting illegal dumping is a major concern that impedes advancement in the municipality. With informal dwellings on the rise, illegal dumping has consequently increased, impacting people's health. The waste resource management feedback loop shows that waste generation reduces available landfill capacity and undermines environmental protection efforts. However, recycling efforts, such as source separation in selected suburbs, diverts waste and home composting further increases the diverted waste, thus, saving on landfill airspace. Alternative technologies can also be utilised to increase the landfill airspace, as illustrated in the environmental protection feedback loop. To assist the City of Cape Town in combatting illegal dumping, case specific studies and particularly, understanding household waste flows and behaviours would be useful. In addition, extending to quantitative system dynamics modelling would support policy design and implementation of intervention projects.

Opsomming

Afvalproduksie in stede bied een van die grootste uitdagings wat stedelike volhoubaarheid betref. Namate die bevolking groei, word al hoe meer afval gegenereer. Afvalbestuur het ’n groot uitdaging vir stedelike en stadsbestuurders geword. Hierdie studie ondersoek die dinamiese faktore wat toekomstige huishoudelike afvalvloeipatrone in die Stad Kaapstad beïnvloed. Dit word gedoen eerstens deur ’n literatuurontleding ten einde die drywers vir afvalvloei te bepaal en deur munisipale afvalbestuur as ’n ingewikkelde sisteem te verken. ’n Benadering wat op kwalitatiewe sisteemdinamika berus en hoofsaaklik kousale lusdiagramme gebruik, is vervolgens ingespan, waarna drie terugvoerlusse wat noodsaaklik vir afvalbestuur is, uitgewys is, te wete: die terugvoerlus vir openbare gesondheid; die terugvoerlus vir afvalhulpbronbestuur; en die terugvoerlus vir omgewingsbeskerming. In die terugvoerlus vir openbare gesondheid is daar bevind dat inwoners se gedragsprobleme rakende die bekamping van onwettige storting ’n ernstige bron tot kommer is en vordering in die munisipaliteit strem. Namate informele nedersettings uitbrei, neem onwettige storting toe, wat ’n impak op mense se gesondheid het. Die terugvoerlus vir afvalhulpbronbestuur toon aan dat afvalgenerering die beskikbare terreinvullingskapasiteit verminder en pogings tot omgewingsbeskerming belemmer. Herwinningspogings soos die skeiding van afvalbronne in gekose voorstede herlei wel die afval, terwyl tuiskomposproduksie die hoeveelheid herleide afval verhoog en gevolglik terreinopvullingsruimte bespaar. Alternatiewe tegnologieë kan ook gebruik word om terreinopvullingsruimte te verhoog, soos daar in die terugvoerlus vir omgewingsbeskerming bevind is. Ondersteuning aan die Stad Kaapstad met die bekamping van onwettige storting aan die hand van spesifieke gevallestudies en ondersoeke na huishoudelikeafvalvloei en -gedrag kan van groot waarde wees. Verder kan beleidsontwerp en intervensieprojekte aangehelp word deur die modellering van die kwantitatiewe sisteemdinamika uit te brei.

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Chapter 1: Introduction

1.1 Background

The global urban population in 2014 was more than 50% of the total global population and with continuous population growth and urbanisation, the population is expected to reach 6.4 billion by 2050 (United Nations, 2014), equating to three-quarters of the world's population (Mesjasz-Lech, 2014). It is estimated that 90% of the increase in urban population will be concentrated in Asia and Africa (United Nations, 2014), which will become 64% and 56% urban by 2050, respectively. Cities are the drivers of a nation's economy and the centres of innovation, where the highest skills are focused (UN-Habitat, 2008). However, for cities to be productive, especially in light of expected urbanisation, a certain level of socio-economic stock such as infrastructure is needed (Hyman, 2011). Rapid urbanisation also presents new challenges for innovation and opportunities to improve the way in which human habitats are shaped (UN-Habitat, 2012). Cities depend on various resource flows to function. Significant resource flows through a city's urban system are water, sewage, solid waste, oil, electricity and building materials for construction (Swilling & Annecke, 2012). Without these interconnected resource flows, cities would grind to a halt (Swilling & Annecke, 2012), as living conditions of people are influenced by these services.

One such challenge is municipal solid waste management, which is claimed as one of the biggest challenges of the urban world (Achankeng, 2003; Dyson & Chang, 2005). The production of waste from inflow of materials into cities is a challenge to urban sustainability. The management of waste as a material output has therefore become difficult for urban and city managers responsible for waste management (UNEP, 2005). Waste generation will continue to grow due to increasing urbanisation and increase in affluence (Phiri, Godfrey & Snyman, 2012).

Several authors have contended that the 20th century saw an increase in urban waste due to factors such as global population increase, a rise in living standards, rapid urbanisation and unprecedented levels of economic activities (Agbesola, 2013; Gutberlet, 2015; Leao, Bishop & Evans, 2001; Mesjasz-Lech, 2014; UN-Habitat, 2010). Addressing this challenge has become a priority for the global environmental agenda in the 21st century due to inadequate infrastructure and service provision in both African and Asian cities (UN-Habitat, 2010). A move towards accelerating sustainable urban transitions is necessary to cater for the increase in urban populations (UN-Habitat, 2014) and the rising generation of urban waste, which presents public health and environmental threats (Gutberlet, 2015; Mesjasz-Lech, 2014; Pai, Rodrigues, Mathew, Hebbar, 2014; Wilson, Velis & Rodic, 2013).

Traditionally, municipal waste management consists of waste generation, collection, transport, transfer, processing and finally disposal. This represents a complex system that is dynamic and multi-faceted and depends on available technology as well as social and economic factors (Ahmad, 2012). Landfill sites result in leachate (contaminated water) from landfilled waste, loss of habitat and consumption of natural resources (Pai, Rodrigues, Mathew, Hebbar, 2014) and have no beneficial use upon closure (Leao, Bishop & Evans, 2004). Despite the need for a move towards sustainable urban transitions, with land as a limited and scarce resource (Leao, Bishop & Evans, 2004), landfill sites are still seen as the preferred method for disposal. This is mainly due to governance issues, high capital investment and operating costs, which normally seek international development aid funding (Wilson et al., 2013).

The development of new landfills proves difficult, as there is increasing competition for land development, thereby putting pressure on land resources in areas surrounding cities (Lea, Bishop & Evans, 2004). What is required is sustainable and integrated waste management (IWM) disposal practices such as thermal processing, energy recovery and variations of mechanical biological treatment facilities to mitigate detrimental environmental impacts and harm to public health and return waste materials as a resource for beneficial use (Wilson et al., 2013).

In South Africa, waste is a significant and growing environmental issue. The volumes of waste have grown steadily and gave rise to nearly 67 million m^3 of waste from 2001 to 2011, with an annual average growth rate of approximately 5% (DEA, 2012). Despite the increase in waste, there is still a backlog in waste service provision with almost 900 000 of households not receiving a basic collection service by 2011 (DEA, 2012). There is still a heavy reliance on landfills, with over 90% of all waste ending up at landfills (DEA, 2012). There are 1 203 general waste landfill sites in South Africa, of which 56.4% are unlicensed (DEA, 2012). There are many licenced sites that are non-compliant with their waste management licence conditions, resulting in negative environmental impacts and pressure on available land resources (DEA, 2012). The national government has set targets for the reduction of waste to landfill in its Medium Term Strategic Framework (2014–2019) (DEA, 2014). This framework aims to protect and enhance our environmental assets and natural resources and to improve waste management by investing in recycling infrastructure and implementing the internationally adopted waste management hierarchy (DEA, 2014). The framework states that the percentage of waste diverted from landfill for reuse, recycling and recovery must be 20% by 2019. The limited capacity for landfill along with the national government's targets for the reduction of waste disposed of at landfill implies that alternatives are needed as a means to deal with municipal solid waste.

The growing environmental issue can be attributed to rapid urbanisation in major cities in South Africa, such as Cape Town in the Western Cape province (City of Cape Town, 2016b; 2017). The City of Cape Town is no exception to the global environmental challenges, including municipal waste management. The main method currently used to manage municipal waste is disposal at landfills with limited recycling activities (City of Cape Town, 2016b; 2017). The recycling activities entail separation at source at almost a third of formal households in the City of Cape Town and public drop-off facilities – residents are encouraged to take their recyclables to such drop-off facilities. Recently a home composting pilot project has been launched as well (City of Cape Town, 2016b; 2017).

The City of Cape Town's environment faces historical challenges such as rapid urbanisation, with a growing number of households requiring municipal services amid increased natural resource constraints (City of Cape Town, 2014; Swilling, 2014). The limited recycling efforts, excluding the home composting pilot project, currently divert 12% of the municipal waste stream from landfill to increase available airspace. However, the total available airspace at the operating facilities is estimated at less than 10 years, below the international benchmark for airspace provision of 15 years (City of Cape Town, 2016b; 2017).

The City of Cape Town Metropolitan Municipality has planned a new regional landfill site, outside Atlantis (City of Cape Town, 2014), and is awaiting licence approval for this facility. The new regional landfill site will assist in carrying out the municipality's constitutional mandate to provide basic services to all its communities (City of Cape Town, 2014). The construction of new landfill sites is a complex and expensive process, but remains an essential service that the City of Cape Town is mandated to deliver. On the one hand, locating new landfill sites too far out of the city would result in increased transport costs for the municipality; on the other hand, there is insufficient land to locate them closer to waste generation areas. Sites must be engineered, with costly containment barriers, and properly operated to prevent the pollution of groundwater or other forms of pollution from occurring.

1.2 Research problem

Solid waste is one significant resource flow in the City of Cape Town and requires urgent attention to cater for the influx of people, as the three operating landfill sites are fast approaching full capacity. In order to properly manage municipal solid waste in the growing city, it is essential to understand the trends in growth and urbanisation in Cape Town. This can assist in estimating waste generation and future needs for disposal facilities in order to promote sustainable waste management for an inclusive urban Cape Town (City of Cape Town, 2014).

> Cape Town currently has several significant environmental challenges, including climate change, waste and pollution, resource depletion and biodiversity loss. Urban environmental problems should be understood as a threat to present and future human well-being, resulting from human-induced damage to the physical environment that originates or is experienced in urban areas. (City of Cape Town, 2014:25)

This study explored the dynamic factors influencing domestic waste flows in the City of Cape Town in providing additional landfill airspace to the already dwindling available landfill capacity in a developing world context of urban growth.

1.3 Research objectives

The objectives of this study were:

1) To examine the drivers of waste flows in the City of Cape Town;
2) To examine existing solid waste management practices in the City of Cape Town; and
3) To explore the dynamic factors influencing future domestic waste flows in the City of Cape Town using causal loop diagrams.

1.4 Significance of the study

The significance of this study is its contribution to the academic field of sustainable development in growing cities through the demonstration of the importance of and need for integrated sustainable waste management (ISWM) planning and practices. Reducing the negative impacts of Cape Town's current waste challenges, such as groundwater contamination, land degradation and methane emissions, will have positive impacts for the residents of Cape Town as well as the natural environment. The City of Cape Town can use this study to inform its waste management system.

1.5 Limitations and assumptions of the study

The research only focused on domestic waste flows in the City of Cape Town. When searching for literature on waste management practices in the City of Cape Town, the majority of reports and documents were available on the municipality's website and the only waste stream on which considerable emphasis was placed was domestic waste. The other waste streams, namely commerce and industry, are blurred in the available literature, and therefore an account of the total waste stream could not be undertaken. This resulted in the research being heavy reliant on grey literature, which is generally not published in the public or peer reviewed journals.

1.6 Research strategy

The research strategy for this study is depicted in Figure 3.1. A literature review (Step 1) was conducted to review the issues of population growth, urbanisation, the drivers of waste flows and sustainable waste management. Further, the literature review substantiated the choice of qualitative system dynamics using causal loop diagrams as a useful way to understand dynamic factors influencing future domestic waste flows in the City of Cape Town. The study investigated current waste management practices in the City of Cape Town (Step 2) to inform the causal loop diagrams (Step 3).

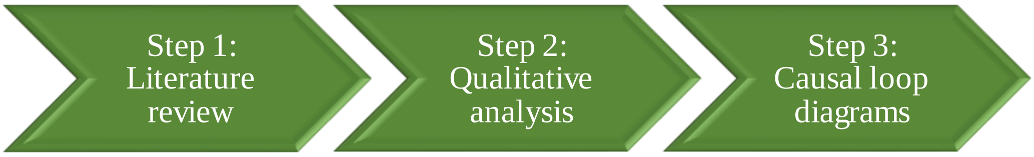


Figure 3.1: Research strategy
Source: Researcher

1.7 Outline of the thesis

Chapter 1 introduced the background to the study, the research problem, the objectives, significance and study scope and the research strategy. Chapter 2 presents the literature review, which includes drivers of waste flows, sustainable waste management and the need for qualitative system dynamics using causal loop diagrams. Chapter 3 presents the methodology conducted and the research methods used for the study. Chapter 4 outlines and presents the results and outcomes of this study. Chapter 5 concludes the study and provides recommendations for further research.

Chapter 2: Literature review

2.1 Introduction

Our future depends on how waste is managed (UNEP, 2015). The generation of waste and its associated problems are found wherever there is a human activity (Ogola, Chimuka & Tshivhase, 2011). This is certainly true in cities that provide opportunity for economic development, a process that inevitably produces waste. The types of problems associated with waste are often varied, based on time and the development of societies of various sizes, and are problems faced in many countries today (Agbesola, 2013). Various documents state that the magnitude of waste-associated problems, as well as the quantities and composition of waste, differs significantly between developed and developing countries (Engledow, 2005; UNEP, 2002), and it is notable that problems are manifested in different ways across different urban settings.

There is no readymade solution for dealing with waste management challenges, as cities are unique, with different types of landscapes and context-specific needs. Developed countries generate almost half of the global waste, while Asian and African countries generate the least waste (European Commission, 2010). Countries in North America and Europe have experienced growth in waste generation of 25% and 14%, respectively, between the years 1995 and 2007. Developing countries in Central and South America saw an increase of 12% between 1998 and 2005, while countries in Asia are expected to experience a staggering growth in waste production of 137% between 1998 and 2025 (European Commission, 2010). This high growth expected is due to the fact that 90% of the increase in urban population will be concentrated in both Asia and Africa.

This chapter investigated the problem of waste at a global and local scale to contextualise the urban waste problem in both developed and developing countries, and to demonstrate the importance of addressing the challenges faced by waste management. The chapter presents a literature review on undesirable consequences of conventional waste management practices that fail to tap into the resource value of waste, as well as examples of countries that have made a paradigm shift towards ISWM practices. It argues that waste must be dealt with in a sustainable manner to safeguard the environment for future generations. The practices to move towards ISWM was also reviewed. The chapter concludes with a discussion of qualitative system dynamics modelling and how causal loop diagrams can contribute to understanding the dynamic drivers essential for planning waste management systems.

2.2 Defining waste

The term 'waste' has many interpretations. The Basel Convention defines waste as "substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law" (UNEP, 2000:6). The European Union (2008:n.p.) defines waste as "any substance or object which the holder discards or intends or is required to discard". These 'substances' or 'objects' are generally classified by their source or origin, their constituent, regulations or material types. The above definitions label waste as something unwanted by the 'holder', therefore assuming a negative connotation to it (Marshall & Farahbakhsh, 2013). However, in the context of integrated solid waste management, such as in the South African context, waste only bears a negative connotation if it cannot be used as a resource. The South African definition of waste has elements of the internationally adopted waste management hierarchy and is expressed by the '3Rs': reduce, reuse and recycle (Marshall & Farahbakhsh, 2013; Wilson et al., 2013).

The South African Department of Environmental Affairs (RSA, 2014:4) defines waste as follows:

(a) any substance, material or object, that is unwanted, rejected, abandoned, discarded or disposed of, or that is intended or required to be discarded or disposed of, by the holder of that substance, material or object, whether or not such substance, material or object can be re-used, recycled or recovered and includes all wastes as defined in Schedule 3 to this Act; or

(b) any other substance, material or object that is not included in Schedule 3 that may be defined as a waste by the Minister by notice in the Gazette, but any waste or portion of waste, referred to in (a) and (b), ceases to be a waste-

    i. once an application for its re-use, recycling or recovery has been approved or, after such approval, once it is, or has been re-used, recycled or recovered;

    ii. where approval is not required, once a waste is, or has been re-used, recycled or recovered;

iii. where the Minister has, in terms of section 74, exempted any waste or a portion of waste generated by a particular process from the definition of waste; or

where the Minister has, in the prescribed manner, excluded any waste stream or a portion of a waste stream from the definition of waste.

Waste is classified into various categories. Typical classifications are municipal waste, hazardous waste and nuclear waste. Photograph 2 depicts the different material types from municipal waste collections. Plastic and paper are the most notable waste materials and offer the potential to be recycled.

Photograph 2: Municipal waste from residential collections
Source: Researcher

The next section describes the flows of urban waste and introduces the notion of linear waste flows versus circular waste flows through cities. The flow of urban waste is normally from residential or industrial sources through to the recovery, recycling or, as a last resort, final disposal of waste and is normally conveyed by infrastructure systems, which are different in different world contexts.

2.3 Urban waste flows

Globalisation and urban growth are seen as the two main drivers of increased waste volumes in cities (Achankeng, 2003). The increased volumes are notably due to increased flows of goods and services needed in growing cities. This is further compounded by a change in lifestyle: As people earn more money, their consumption increases and their consumption patterns change, resulting in increased production of waste and more variety of waste flows (Achankeng, 2003; Swilling & Annecke, 2012). As globalisation increases, it has become necessary to re-imagine sustainable urban transitions in cities and to capture the most effective interventions (UN-Habitat, 2014). Figure 2.1 depicts the current unsustainable linear flow of material inputs and outputs with both consumption and pollution at high rates. Linear flows can be seen as unsustainable because of the limited resources available; waste is still not being recycled and reused and therefore produces leachate from landfills, which contributes to climate change and the waste of valuable land.

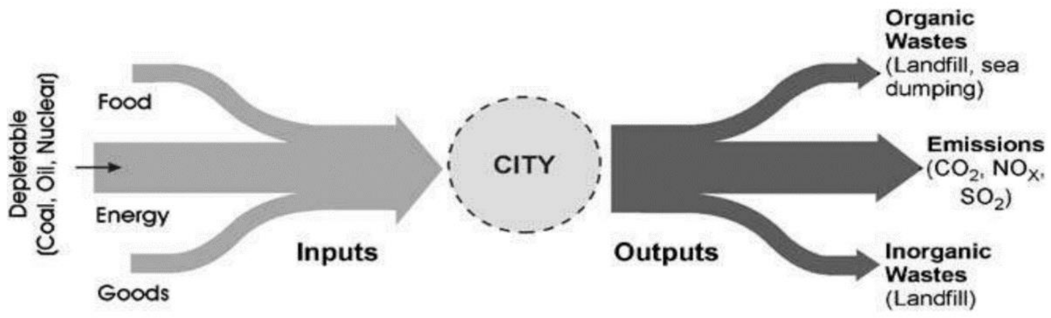


Figure 2.1: The linear metabolism of cities
Source: Doughty and Hammond (2004)

In the past, many cities have been built on this linear metabolism structure. Now, with the ‘second urbanisation wave’ in developing countries and limited landfill airspace available, it is impossible to continue with this unsustainable linear flow trajectory. Interventions are required to reduce the output of waste materials, as shown in Figure 2.2. Such interventions would make use of circular flows to recycle and reuse waste as early as possible.

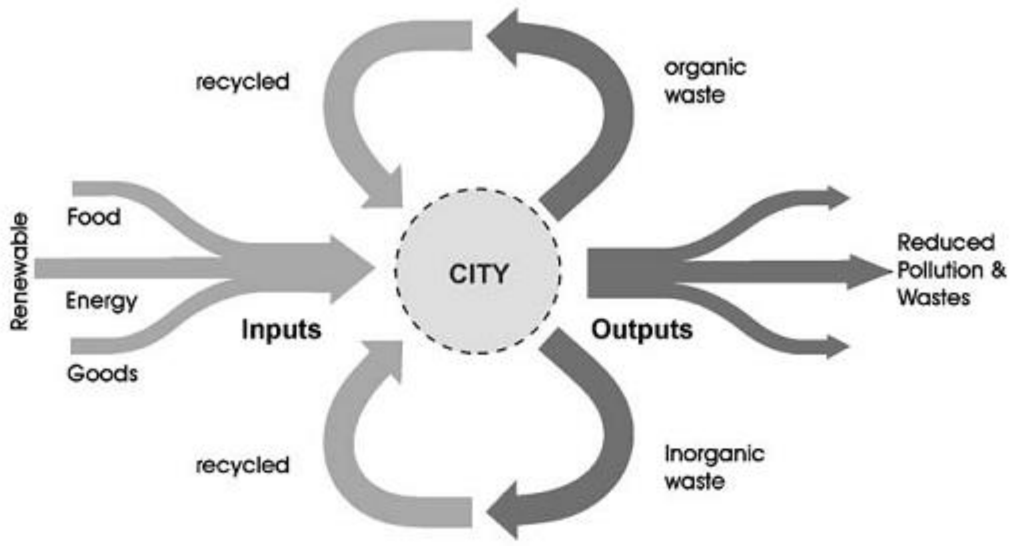


Figure 2.2: The circular metabolism of cities
Source: Doughty and Hammond (2004)

Figure 2.2 depicts a circular metabolism of material flows with a reduction of new inputs with the use of renewable energy as opposed to the use of conventional coal, oil and nuclear in the linear metabolism, and maximisation of recycling of organic and inorganic waste, ultimately leading to fewer outputs. This model is the ultimate sustainable waste management approach, as it 'closes the loop' by returning both organic and inorganic waste to beneficial use through recycling (Wilson, 2007). This ensures landfill sites having extended lifespans and a cleaner environment, and as a result achieves sustainable development in cities. Girardet (1996) argues that linear inputs and outputs of cities are unsustainable. Doughty and Hammond (2004) point out that circular metabolism is more desirable than the linear approach, as inputs are efficiently harnessed and waste products are reduced, reused or recycled. However, Troschinetz and Mihelcic (2009) are of a different opinion and state that recycling as one form of achieving sustainable municipal solid waste management depends greatly on where one lives.

Developed countries have recycling activities that are part of people's daily lives, in which source separation and drop-off facilities are in close proximity to residential areas (Troschinetz & Mihelcic, 2009). This is heavy loaded with technical applications, policies and economic incentives. In contrast, developing countries struggle with behaviour problems such as a lack of interest in recycling (Troschinetz & Mihelcic, 2009). In most developing countries the informal sector, which consists of waste pickers among others, collect recyclables at landfill sites and kerbside collection bins and sell the recyclables to buy-back facilities if they have transport or to middlemen who transport the waste to recyclers (Troschinetz & Mihelcic, 2009). In this way, these waste pickers rely on recyclables to enable their livelihood.

2.3.1 Defining municipal solid waste

The definition of municipal solid waste varies between countries (UN-Habitat, 2010) and the variation is evident in most international literature reviewed for this study. The definition is often used when referring to sources of waste from households, commerce, industry and agriculture and construction activities (Intharathirat et al., 2015; Karak, Bhagat & Bhattacharyya, 2012; Ogola et al., 2011; Sufian & Bala, 2007; UNEP, 2005). The definition also evolves over time due to its heterogeneous (i.e. household waste) and homogenous (i.e. industrial and agricultural waste) nature and can therefore be termed a ‘working definition’. Further context is given in the UN-Habitat’s report (2010:6), which defines municipal solid waste as follows:

> [W]astes generated by households, and wastes of a similar nature generated by commercial and industrial premises, by institutions such as schools, hospitals, care homes and prisons, and from public spaces such as streets, markets, slaughter houses, public toilets, bus stops, parks, and gardens.

Apart from the definition, it is important to understand the composition of municipal solid waste, as it provides an indication of the rate of recycling, per material type, in both developed and developing countries. Vesiland and Worrell (2002) refer to municipal solid waste as solid waste produced by communities and explain that it is made up of mixed household waste, recyclables, household hazardous waste, commercial waste, bulky waste, construction and demolition waste and garden green waste, shown in detail in Table 2.1.

Table 2.1: Composition of municipal solid waste

Composition	Types of material
Mixed household waste	Kitchen waste, fabric and packaging
Recyclables	Newspaper, cans (aluminium and metal), plastic, cardboard, glass
Household hazardous waste	Paints, chemicals
Commercial waste	Businesses, industry
Bulky waste	Refrigerators, rugs
Construction and demolition waste	Bricks, sand, concrete
Garden green waste	Leaves, tree cuttings

Source: Adapted from Vesiland and Worrell (2002) and Engledow (2007)

For the purpose of this study, municipal solid waste refers to mixed household waste (including recyclables and household hazardous waste), commercial, and construction and demolition waste. Household waste refers to mixed household waste, recyclables, household hazardous waste and garden green waste.

Figure 2.3 indicates the composition of municipal solid waste for various income cities, adapted from the UN-Habitat report, *Solid waste management in the world's cities: Water and sanitation in the world's cities* (2010). Figure 2.3 shows that organic waste dominates the composition of municipal solid waste in both low-income and middle-income countries, while recyclables (paper and cardboard, plastic, metals, glass) dominate in the high-income countries. As countries get richer, their consumption patterns increase. Low-income countries are predominantly reliant on organic waste and middle-income countries on paper and cardboard. Because middle- and high-income groups make use of higher proportions of materials that can be recycled, this is where recycling initiatives could be focused.

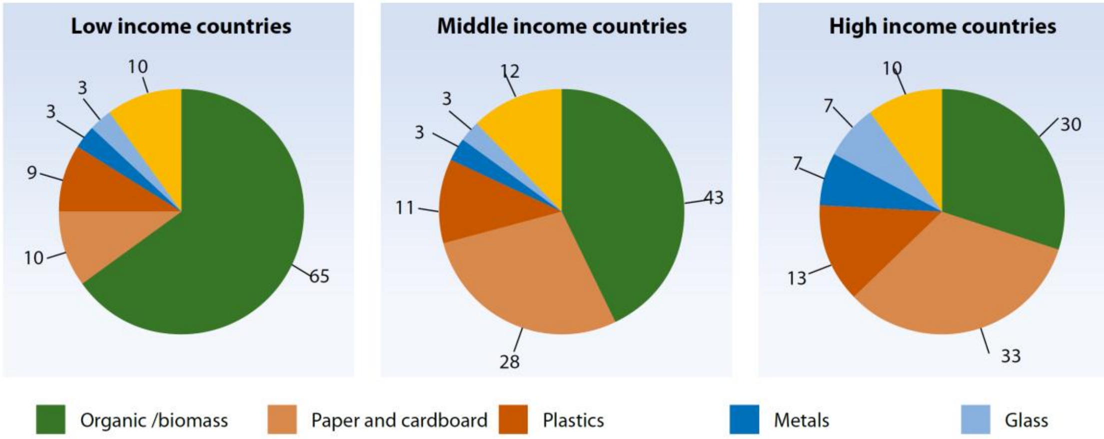


Figure 2.3: Composition of municipal solid waste (%) in relation to income per country category

Source: United Nations (2011)

City-level waste compositions are shown in Table .2. The proportion of organic wastes produced in each city is as follows: Delhi 81%, Nairobi 65%, San Francisco 34% and Rotterdam 26%. The cities of Delhi and Nairobi are both low-income cities, therefore organic waste dominates the waste stream. This trend is confirmed at country level by recent waste characterisation surveys conducted in developing countries showing high organic waste generation rates, such as in Ghana with 61% (Miezah, Obiri-Danso, Kádár, Fei-Baffoe, Mensah 2015) and Lagos, Nigeria with 55% (Agbesola, 2013).

Table 2.2: Waste compositions for various income cities

Income category	City	Paper (%)	Glass (%)	Metal (%)	Plastic (%)	Organics (%)	Other (%)	Hazardous waste (%)	Residual (%)	Total (%)
High	Adelaide, Australia	7	5	5	5	26	52	0	0	100
Low	Nairobi, Kenya	6	2	1	12	65	15	0	0	100
High	Rotterdam, Netherlands	27	8	3	1	26	19	0	0	100
High	San Francisco, USA	24	3	4	11	34	21	3	0	100
High	Tompkins County, USA	36	6	8	11	29	11	0	0	100
Low	Delhi, India	7	1	0	10	81	0	0	0	100
High	Varna, Bulgaria	13	15	10	15	24	23	0	1	100
Low	Moshi, Tanzania	9	3	2	9	65	5	0	7	100

Source: UN-Habitat (2010)

The UN-Habitat (2010) indicates that many cities' waste production data are unreliable, as data are seldom captured due to inconsistencies in recording or because not all waste are being accounted for, particularly that produced through informal activities or lost in the system. However, there are cities with sound government systems with reliable data through regular monitoring and capturing of weighbridge data at waste management facilities. Low- and middle-income countries do not always have the necessary measuring equipment and therefore waste is estimated based on the size of collection vehicles (UN-Habitat, 2010).

It is evident that the types of municipal solid waste produced are similar throughout the world. However, generation rates and proportions of waste materials generated vary between countries and cities, typically based on the level of economic development (Sufian & Bala, 2007). It is generally accepted that consumption patterns rise with affluence. The dynamics that connect affluence and consumption patterns are discussed in the next section.

2.3.2 Municipal solid waste generation

Resource management strategies start by strengthening awareness of natural limits of materials and energy sources. This awareness was present in ancient times, but has gradually been lost as communities became affluent and raw material and energy become more affordable (UNEP, 2002). It is unlikely that the situation will change unless better care of global resources is acquired. Resource management strategies extend far beyond waste management, as municipal solid waste is a by-product of the extraction of raw materials and energy. If manufacturing processes continue with the current trajectory of 'just extraction' as opposed to changing the design of products, resource conservation goals will never be met.

Gutberlet (2015) argues that local governments have limited power over consumptions patterns, and that the concentration is mostly on deciding which are the most appropriate waste management technologies and strategies to be implemented. It is with this in mind that an understanding of waste generation patterns across the globe can be gained. In general, there is a direct relationship between population and the amount of domestic waste generated. As the population grows, so does waste; however, consumption patterns also increase with a rise in living standards. Various studies have suggested this relationship (Ahmad, 2012; Buenrostro, Bocco & Vence, 2001; European Commission, 2010; Grazhdani, 2016; Suthar & Singh, 2015) and the importance in determining the type of waste management system for an urban place.

Population and waste generation rates for the same cities discussed in Section 2.3.1 are depicted in Table 2.3. It is notable that the high-income cities have higher generation rates (kilograms per capita per day [kg/capita/day]) than middle- and low-income countries.

Table 2.3: Waste generation for various income cities

Income category	City	Population	Kilograms per capita		Kilograms per household	
			Year	**Day**	**Year**	**Day**
High	Adelaide, Australia	1 089 728	490	1.3	1176	3.2
Low	Nairobi, Kenya	4 000 000	219	0.6	1314	3.6
High	Rotterdam, Netherlands	582 949	528	1.4	1030	2.8
High	San Francisco, USA	835 364	609	1.7	1400	3.8
High	Tompkins County, USA	101 136	577	1.6	1340	3.7
Low	Delhi, India	13 850 507	184	0.5	938	2.6
High	Varna, Bulgaria	313 983	435	1.2	1131	3.1
Low	Moshi, Tanzania	183 520	338	0.9	1386	3.8

Source: Adapted from UN-Habitat (2010)

As developing countries develop, their generation rates also increase. These are influenced by a change in consumption patterns fuelled by globalisation (Achankeng, 2003). Seasonal changes also have an effect on organic waste, as this changes over seasons and different climatic conditions (Troschinetz & Mihelcic, 2009; UNEP, 2002).

2.4 Waste management

Many governments in developing countries are faced with deteriorating environmental problems and health hazards, such as illegally dumped or uncollected waste (Achankeng, 2003). Many of them are unable to deal with increasing amounts of waste generated, as they are still vested in traditional approaches.

Wilson et al. (2013) allude that solutions for solid waste management in developing countries need to be designed for the specific local circumstances and conditions. They argue that ‘local solutions can work’, referring to a remote municipality in southwestern Nepal, called Ghorahi, which has limited human and financial resources, but has a strong vision and commitment with active participation of stakeholders (Wilson et al., 2013). The municipality managed to develop a modern waste management facility without foreign financial aid (Wilson et al., 2013). The facility includes a waste sorting and recycling area, sanitary waste disposal with on-site leachate detection, collection and treatment and a buffer zone. Geological studies were undertaken to identify the most suitable site. The municipality convinced the Ministry of Local Development to assist with funding for the construction of the waste processing and disposal facility (Wilson et al., 2013). The facility has been in operation since 2005 and has a landfill committee, which includes residents and key stakeholders, to monitor and ensure that the facility is properly managed.

Phiri et al. (2012) describe the major constraints to waste management in developing countries. Developing countries struggle with lack of funds and knowledge, which places constraints on dealing with waste, while in developed countries such as Europe and North America, the major constraint is the availability of land. In order to implement effective interventions to manage waste better, the first step is to collect vital data about the type of waste streams and generation rates in the city (Phiri et al., 2012).

The following sections explore traditional solid waste practices as well as ISWM practices in both developing and developed countries.

2.4.1 Traditional municipal solid waste management

Historically, municipal solid waste has been viewed as an undesirable product to be disposed of in open and uncontrolled dumps and landfills (Engledow, 2007; Inghels & Dullaert, 2010; UNEP, 2002). The practice of open dumping is cheap and requires no planning (Sufian & Bala, 2007), but degrades the environment, undermines people's health and quality of life, and is a breeding ground for vectors of disease. Traditional waste management, also regarded as a reductionist approach, only considers waste generation, collection and disposal (Hyman, 2011). It limits its understanding of the waste system to a set of networked infrastructures that convey waste (Hyman, 2011). However, while there is a move towards the recovery of waste, open dumps and burning of waste are still the most preferred methods of waste disposal in many countries (UN-Habitat, 2010).

The recovery of waste varies between developed and developing countries. Developed countries tend to rely on expensive incineration and waste-to-energy technologies to recover their waste, while developing countries have active informal sectors with recycling rates that are comparable to that of developed countries, but at no cost to municipalities, thereby offering huge savings in terms of the provision of waste management services (UN-Habitat, 2010).

Informal recycling provides a livelihood to many people living in poverty in cities. The promotion of the informal waste recycling sector is important in reducing the amount of waste collected and disposed of by municipalities (Engledow, 2007). Promoting this important well-being strategy for waste pickers assists them to make an income from collecting and selling recyclables. Global initiatives, such as in the city of Curitiba in Brazil, with a rewards-based disposal system to overcome social and environmental challenges in the city, have received many accolades. Gratz (2013) describes this initiative as follows:

> The operator is undoubtedly poor but rather than dependent on sheer charity, this hard worker is one of approximately 10,000 Curitibanos who collect trash, deposit

> it at a recycling center and obtain fresh food and bus tickets in exchange. For every 4 pounds of recycling garbage they deliver, they get a pound of fruits, vegetable and eggs, and for every 2 liters of used oil and plastic bottles turned in, 1 kilogram of the same fresh foods are exchanged. In these carts, only cardboard is carried but people collect by other means glass, metal, paper, plastic, used oils and contaminated material for recycling as well. … An estimated 70 percent of Curitiba's garbage is recycled. Thirty to forty percent of that garbage, approximately 900 pounds a month, is deposited here. Garbage trucks deliver three times a week. There are four other government facilities like this one and 13 private ones elsewhere in the city, all of which process the other 60 percent of the city's recycled trash. There are 23 sites around the city, including nine bus terminals, where individuals bring their collections. … The trash collectors and street sweepers are only part of a much broader official city mindset that reflects both a huge culture of recycling and progressive environmental policies. School children, for example, bring plastic to school for recycling and get back at Christmas time toys made of recycled plastic. No better way can be devised to involve kids in the culture of recycling at an early age. The kids, in turn, educate the parents. All public and private schools are required to separate the garbage. The environmental mindset can be seen across the board, even in shopping malls. Fast food eateries serve on real plates with real silverware. Styrofoam is a rarity. Stores and museum shops sell products made from recycled goods. The thinking is pervasive.

A combination of systems exists to effectively regulate waste from its source of generation, and in this instance collection from households and transfer and transport thereof to final disposal at landfill. The proper handling of waste from its collection point to final disposal has been identified as a challenge in many countries across the world (Agbesola, 2013).

'Open dumps' are very prevalent in developing countries in Latin America, Africa and Asia, unlike in developed countries in North America and Europe (United Nations, 2011). However, it is noted that in Europe large numbers of open dumps are prevalent. What is interesting is the high portion of sanitary landfills in North America, indicating the future is still seen as landfilling (United Nations, 2011). Latin America has more sanitary landfills than Africa and Asia (United Nations, 2011). Although there is limited landfill capacity in developing countries, open dumps continue to be the main method of waste disposal, as collection of waste alone takes up 80 to 90% of solid waste management budgets (United Nations, 2011). Also, in developing countries, despite at least 20 to 50% of the recurring municipal budgets being spent on solid waste management in municipal jurisdictions, only approximately 50% of the urban population is covered under these services (United Nations, 2011).

Seadon (2010) provides a few examples of traditional practices in Auckland, New Zealand, which are also common in other countries, as follows:

- More effort spent on conducting annual waste characterisation surveys when waste management practices do not change
- An increase of waste generation, resulting in undervaluing the side effects of interventions (e.g. upgrading from 40-litre to 240-litre collection containers)
- Short-term goals instead of long-term sustainability thinking (waste information on quantities of waste recycled rather than focusing on change in packaging design)
- Underestimation of time lags between intervention and effects (waste strategy was reviewed for progress in 2004, a year after institution, and again in 2006)
- Reliance on linear extrapolation of waste data over the short term and long term.

Seadon (2010) maintains that as waste management is a complex system, the above are common shortfalls and should not be ignored.

Waste management forms an integral part within the element of environmental order, one of the three pillars of sustainable development (Mesjasz-Lech, 2014). A paradigm shift is necessary to achieve ISWM to effectively manage waste. However, there is a general agreement on best practices (Leao et al., 2001) and developed countries' increased recognition that waste is a resource with economic value (Inghels & Dullaert, 2010).

2.4.2 Integrated sustainable waste management

The first decade of the 21st century saw the concept of sustainable waste management becoming the norm in developed countries. Wilson et al. (2013) studied the term 'sustainable waste management' in a variety of contexts and Table 2.4 indicates two thematic uses of this term.

Table 2.4: Different uses of the term sustainable waste management

Thematic use	Description	Selected references
Integrated (solid) waste management (using the waste management hierarchy)	Integrating solid waste management according to principles of the waste hierarchy, combining waste prevention or reduction, reuse, recycling/composting, energy recovery and disposal, or discussing the role of particular technological solutions	Smith (1990); Johnke (1992), USEPA (2002); Heimlich et al. (2005) Memon (2010); Consonni et al. (2011)
Integrated sustainable waste management (ISWM)	Integrating across three dimensions, all the elements of the waste management hierarchy, all the stakeholders involved and all the 'aspects' of the 'enabling environment' (political, institutional, social, financial, economic and technical). Used particularly in developing countries	Schübeler et al. (1996); Van de Klundert and Anschütz (2001); Anschütz et al. (2004); Scheinberg et al. (201b)

Source: Wilson et al. (2013)

The term 'integrated' found its origin during the 1970s (Murray et al., 1971; Tobin & Myers, 1974, as cited in Wilson et al., 2013) and has since been broadly accepted until it became standard in the mid-2000s. Wilson et al. (2013) note that the terms 'integrated' 'waste' and 'management' have been used in at least 244 published journal papers by March 2012. This implies addressing all of the levels of the waste management hierarchy, recognising that waste is not a homogeneous mass but rather a mix of different material that should be treated differently, that is, some materials should not be produced at all, while others should be reduced, reused and recycled (Gertsakis & Lewis, 2003). Such a system involves a systems approach, discussed later in Section 2.7.

IWM follows the principles of the waste management hierarchy, whereas ISWM integrates across three dimensions, namely the scope in the economic context, the actors in the political context and how the socio-cultural context is being incorporated. ISWM is essential to the effective management of waste (Marshall & Farahbakhsh, 2013). However, it is a complex task for governments and institutions in developing countries, especially those with the absence of strong political drivers, causing political instability compounded by non-functioning policies due to weak institutional structures that are already overburdened with increasing demands for services due to population explosion (Marshall & Farahbakhsh, 2013).

As an illustration, the World Bank, which supports international funding to many developing countries had a few unsuccessful projects in the 1990s. To mention a few are projects in the Philippines, Mexico and Sri Lanka, which received financial aid for various projects. Due to weak institutions, governance issues and a lack of financial capacity to sustain implemented projects, when funding was expended, many projects came to a halt to due to continuous capital and operational expenditure required (Marshall & Farahbakhsh, 2013). The traditional waste management approach is not designed to handle complexity (discussed in Section 2.4.1). The generation of waste and the collection and disposal thereof are considered to operate independently, even though they are interconnected and influenced by one another (Marshall & Farahbakhsh, 2013).

2.4.3 The waste management hierarchy

All the principles of the waste management hierarchy are addressed in IWM and ISWM practices, as stated in Section 2.4.2 Waste management practices in the waste management hierarchy are arranged in descending order of priority and are prioritised, with waste avoidance and reduction receiving the highest priority and treatment and disposal seen as the least desired process in the hierarchy (see Figure 2.4).

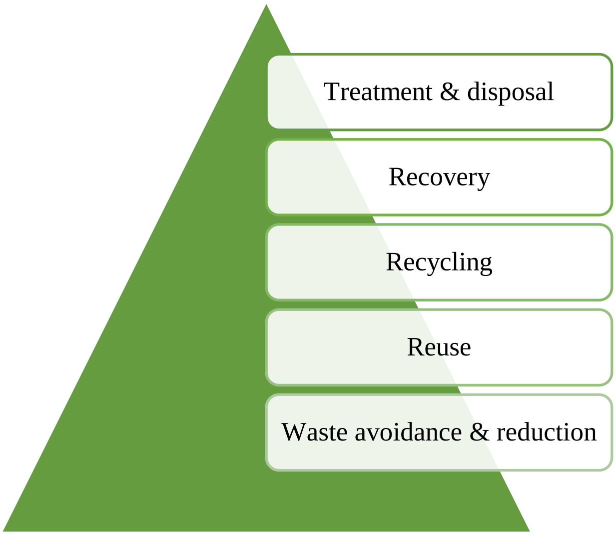


Figure 2.4: Waste management hierarchy
Source: Adapted from DEA (2011)

The most desired practice is waste avoidance and reduction, focusing on changing the packaging design, resulting in fewer inputs of materials, as opposed to heavy reliance on quantities of waste recycled. The next stage is the reuse of waste by removing the material from the waste stream and using it as a secondary material in a new process. Recycling follows next, which is also the stage in which most municipalities are actively involved. Here items are separated from the waste stream such as kerbside collection of recyclables and are further sent for processing. Recovery involves reclaiming components of an item or using the waste as fuel. The least desired option is disposal of waste that cannot be reused, recycled or recovered (DEA, 2011). The ultimate goal is to shift away from landfilling and to use waste as a resource.

2.4.4 Municipal waste management as a complex system

A broad definition for a system is "any object which has some action to perform and is dependent on a number of objects called entities" (Singh, 2009:1). Waste is complex and dynamic by nature, as it is dependent on available technology for safe removal and disposal, as well as social and economic factors, and is therefore seen as a complex system. Waste collection, treatment and disposal can be seen as entities of the waste management system. Each entity has its own properties or attributes, for example the safe collection and removal of waste ensure that waste is collected timeously and therefore does not impact negatively on the environment and the health of people. The collection, treatment and disposal of waste in itself is a complete system; however, if the two are combined, joined in some interdependence, then the three systems become a large system. An example of these various elements is shown in Figure 2.5.

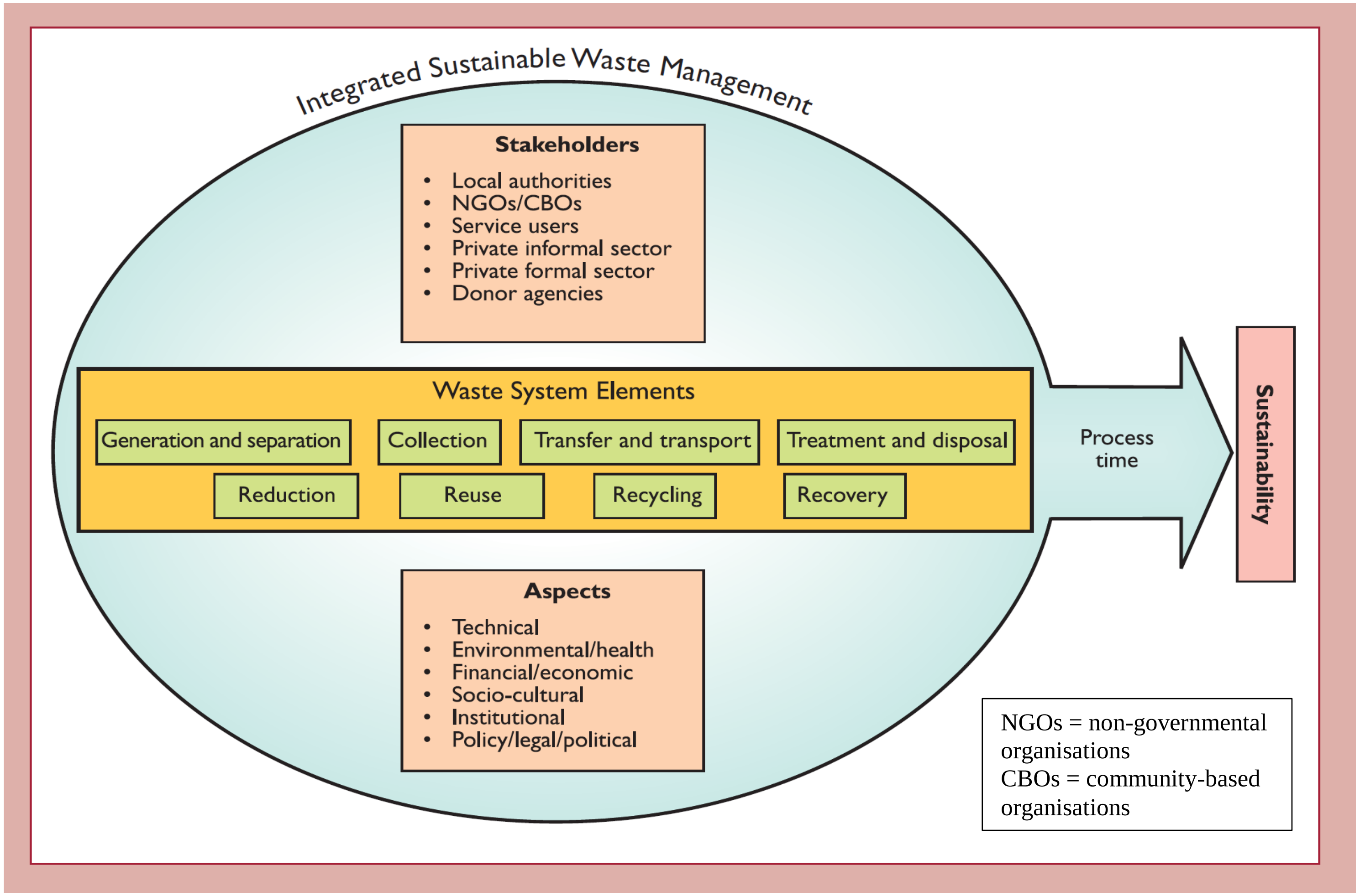


Figure 2.5: Elements of an integrated sustainable waste system

Source: UN-Habitat (2010)

According to Marshall and Farahbakhsh (2013), developing countries have applied various analysis tools to analyse existing solid waste management systems since the 1960s. However, these systems were particular and only focused on the economic and environmental aspects of solid waste management (Marshall & Farahbakhsh, 2013). Pires, Martinho and Chang (2011) state that integrated sustainable solid waste management practices at stages from planning, design, operation and decommissioning are necessary. This would allow government and industry to meet "common needs of waste management" by recycling and encouraging renewable energy in order to preserve the natural ecosystem (Pires et al., 2011:1034). This can be achieved by analysing the system as a whole, as the phases are interrelated and a development in one area affects activities in another area (Pires et al., 2011; UNEP, 2005).

Sustainable management of municipal solid waste has increasingly become a necessity in all phases of the system, from planning to design, collection services, transfer and transportation, to the operation and decommissioning of landfills (Seadon, 2010). This is necessary in order to meet the sustainability goals in the future. In order to achieve these goals, the technical and non-technical components of a sustainable waste management system should be analysed as a whole, as traditional approaches lack long-term thinking and flexibility (Seadon, 2010).

2.4.5 Municipal solid waste: Recovery of recyclables

As stated earlier, recycling is one form of ISWM and also ranked high in the waste management hierarchy (Figure 2.5). This section explores recovery rates in various developing countries as well as the factors influencing recycling as one element of ISWM.

Troschinetz and Mihelcic (2009) identified various recovery rates from 13 developing countries, as shown in Table 2.5. Troschinetz and Mihelcic (2009) note that there are at least 12 factors that influence recycling as one element in achieving sustainable waste management in developing countries: (i) presence of policies, (ii) financial sustainability, (iii) understanding of the composition of waste, (iv) efficient waste collection services, (v) awareness and education, (vi) socio-economic profiles of households that link human behaviour to handling of waste, (vii) effective public–private partnerships, (viii) trained personnel, (ix) long term integrated waste management plan, (x) understanding of the local recycling market, (xi) technology and labour force and (xii) availability of land (Troschinetz & Mihelcic, 2009). All of the above factors are equally important to sustain recycling over the long term.

Table 2.5: Municipal solid waste: Recyclables recovered in 13 developing countries

Country	Municipal solid waste recovery (%)				
	Overall	Paper	Plastic	Glass	Metal
Botswana	x		90		65
Brazil	41	30	20[a]	20[b]	49[c]
China	7–10	x			x
Guyana	x			x[b]	x
India	x				
Indonesia	x	x	x	x	x
Iran	x	x	x		
Mongolia	x				
Nepal	5				
Philippines	13	x	x	x	x
Sri Lanka	x	x	x	x	x
Thailand	15	28	14	18	39
Turkey	x	36	30	25	30
Vietnam	13–20	x	x	x	x

Percentage numeric values provide quantitative recovery rates.
X symbol (x) qualitatively signifies recycling activity occurs either overall or for a particular material.
[a] Recovery of plastic beverage bottles only
[b] Recovery of containers only
[c] Recovery of aluminium cans only

Source: Troschinetz and Mihelcic (2009)

In Table 2.5 the "x" refers to the existence of recyclable material recovery in a country and the numbers presented are the percentage material recovery rates (Troschinetz & Mihelcic, 2009). It is clear from Table 2.5 that the markets for various recyclables are not the same in all the developing countries listed. For example, paper and glass are not being recovered for recycling in Botswana, whereas paper and glass recycling is very prevalent in countries such as Brazil, Turkey and Thailand (Troschinetz & Mihelcic, 2009).

2.5 Drivers of waste flows

The term 'driver' or 'driving force' is a "human activity that is generated to satisfy a need" (UNEP, 2009:57). 'Drivers' are activities that fulfil the needs for shelter, food and water, but also activities to satisfy the need for mobility, entertainment and culture (UNEP, 2009). The term 'driver' or 'driving force' in the context of municipal solid waste management refers to macroeconomic development that causes or drives changes in waste generation. The UNEP (2009) states that typical drivers in waste generation are population growth, industrialisation (resource extraction and processing), urbanisation and lack of adequate infrastructure, whereas intermittent driving forces are activities such as events and tourism (UNEP, 2009).

Various authors attribute the changes or trends in waste generation to numerous factors. A concise overview, to the best of the researcher's knowledge, of the use of the term 'trends in waste generation' or 'changes in waste generation', in a variety of contexts, is outlined below:

- There seems to be a strong relationship between contributing factors of waste generation such as economic activities, population growth, household income and number of people per household. Therefore, population growth affects household income and household income impacts waste generation per person, and a higher-income household tends to produce higher amounts of waste. Conversely, higher-income households also tend to achieve higher recycling participation rates (Dyson & Chang, 2005).

- Socio-economic drivers of waste generation are gross domestic product (GDP), population size, average household size, degree of urbanisation, private consumption, government consumption, population consumption and employment (OECD, 2002).

- Urban population, GDP and consumption levels seem to have a strong correlation with waste generation. The consumption levels of a population have a close relationship with waste generation. Higher consumption levels of residents generate more municipal solid waste, therefore the consumption levels of high-income residents affect generation quantity (Wei, Xue, Yin & Ni , 2013).

- Population growth and rapid changes in lifestyle change the composition of waste and increase waste quantities (Oyoo, Leemand & Mol, 2011).

- Population density is likely to positively impact on waste generation (Mazzanti & Zoboli, 2008).

- Population growth gives rise to an increase in waste production (Lea et al., 2004).

- The improvement of the living standards of residents leads to large municipal waste outputs (Lin & Ying, 2013).

- Changes in lifestyle mean that municipal waste increases rapidly, and the composition of waste also changes (Ahmad, 2012).

From the above literature it is evident that there are varying views on household consumption as a driver of municipal waste generation, for example population density gives rise to an increase in waste production and generation, whereas affluence leads to large waste outputs. Furthermore, Mazzanti and Zoboli (2008) categorised three drivers of waste, namely economic, socio-economic and political drivers.

Typical economic drivers are consumption per capita and share research and development spending in GDP. Socio-economic drivers are population density, urban population degree and household size. Political drivers include legislation that promotes waste prevention such as the waste management hierarchy, where waste prevention is the most desired option; however, source separation and landfill diversion policies have dominated the field (Mazzanti & Zoboli, 2008). Figure 2.6 summarises the various drivers discussed above.

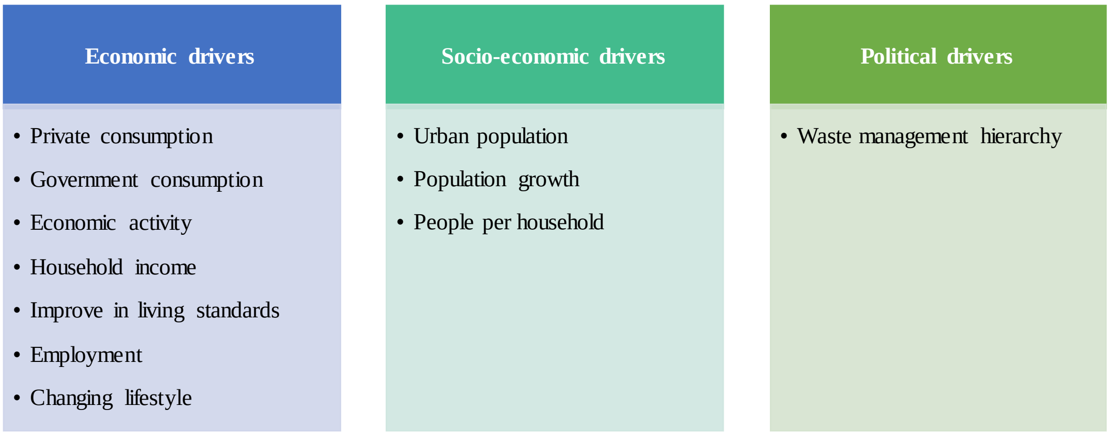


Figure 2.6: Drivers of municipal solid waste flows
Source: Compiled by researcher

As a result of the various drivers of waste generation, constant pressure is placed on municipalities to provide additional services as cities expand. Although various countries and municipalities have made significant strides to improve waste management practices, improvement is still needed to provide a waste collection service to communities. The United Nations Environment Programme (UNEP) developed a framework to analyse and identify gaps in the current system in order for the system to work sustainably over the long term (Wilson et al., 2013), represented in Figure 2.7.

This first triangle in Figure 2.7 comprises three key physical components of a waste management system, linked to key drivers. The physical components are:

- waste collection services that are driven by public health;
- environmentally sound disposal through protection of the environment during treatment and disposal; and
- the 3Rs of the waste management hierarchy, closing the loop and returning organic and inorganic waste to beneficial use (Wilson et al., 2013).

The second triangle focuses on three governance aspects that need to be addressed to deliver a well-functioning system. The system as a whole is required to:

- be inclusive by extending to stakeholders to contribute as users and providers;
- rest on a base of sound institutions and proactive policies; and
- be financially sustainable, cost-effective and affordable (Wilson et al., 2013).

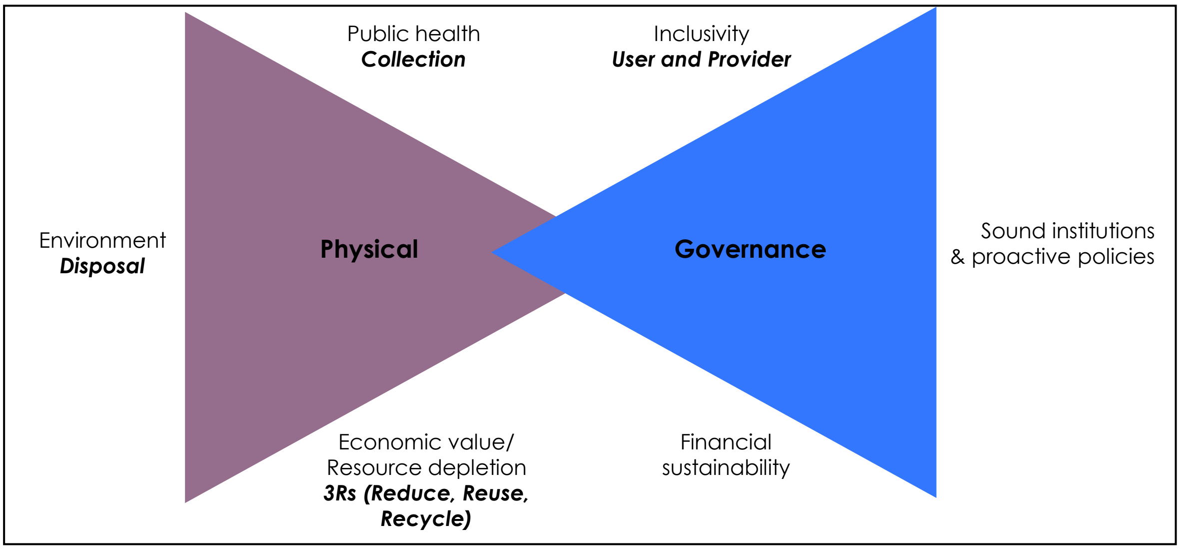


Figure 2.7: Two triangles representation
Source: Adapted from Wilson et al. (2013)

The physical element discusses the three primary driving forces for the development of an ISWM system, namely waste collection, waste disposal and the reduction, reuse and recycling of waste (UN-Habitat, 2010). This element provides the physical basis for the governance aspects to be addressed for the system to work sustainably over the long term.

2.6 Consequences of poor waste management on human and environmental health

The undesirable consequences of poor waste management practices that fail to tap into the resource value of waste affect air, soil and water quality (Alam & Ahmade, 2013). Uncontrolled disposal and burning of waste contribute significantly to air pollution (Alam & Ahmade, 2013; Karija & Lukaw, 2013; UN-Habitat, 2010).

The disposal of biodegradable waste to landfill leads to anthropogenic greenhouse gas emissions from the anaerobic decomposition of organic waste (Intharathirat et al., 2015; Karija & Lukaw, 2013; UN-Habitat, 2010) and forms leachate, which in turn contaminates surface and groundwater. Public health is affected by uncollected waste in dense informal settlements where waste is illegally dumped, causes offensive smells, clogs up drains and causes flooding, which attracts vectors and rodents and leads to the spreading of waterborne diseases, which may lead to child diseases and mortality (Intharathirat et al., 2015; Karija & Lukaw, 2013; UN-Habitat, 2010).

Sound waste management contributes towards the well-being of people and those working in the waste sector (UN-Habitat, 2010). Controlled disposal by means of sanitary landfills, well-established collection areas and increased collection coverage, where disposal is still open dumping, needs to be adopted to suit the local conditions of the city and improve overall sanitation and public health.

2.7 Modelling urban waste

Forecasting waste generation trends with accuracy over time is key to successful waste management planning (Kaushal, Varghese & Chabukdhara, 2015). However, Dyson and Chang (2005) argue that this is a challenge in fast-growing cities as a result of population growth, economic development and changes in employment and household sizes and the impact of waste recycling.

Reliable models are needed to predict the impacts growing cities have on waste management (Dyson & Chang, 2005). Intharathirat et al. (2015) noted that failure to obtain reliable historical waste generation data may lead to difficulties in developing accurate forecasting models, some of which are increased environmental impacts, over- and under-capacity estimations of waste treatment facilities and irrelevant policies (Intharathirat et al., 2015).

Rimaityte et al. (2012) noted that the process of forecasting waste is often problematic, as it is usually aggravated by rapidly changing parameters of waste management systems, especially in areas of rapid economic development, relating to affluence and seasonal impacts. Factors affecting forecasting of waste are the following:

- Availability and quality of data, including waste data and socio-economic and demographic indicators
- Type of data, whether random or continuous
- Relationships of various parameters of waste generation
- Changes to be expected in the waste management field.

Dyson and Chang (2005) argue that trends in the economy, production of waste, growth in population and recycling in terms of municipal solid waste generation are useful advances to practise solid waste management and therefore different relation tendencies exist. In order to identify the most appropriate methodology for this study, by understanding the various influencing factors that affect waste flows, various modelling methodologies were examined. Regression methods have been widely used to forecast waste generation due to their simple algorithms; however, this type of analysis cannot learn from new data or adapt to changing situations (Intharathirat et al., 2015).

Escalante (2012) points out that the lack of adequate data and computational tools to assist decision makers has previously limited the potential for forward planning. As a result, attention has been drawn to different ways of analysing data, such as linear spreadsheet analysis, process engineering models, material flow analysis and lifecycle assessments, and in recent years the application of system dynamics modelling (Escalante, 2012). Linear spreadsheet analysis is a time-series method that uses only waste generation quantities and their corresponding time; however, this method is not convincing as to why future quantities will follow the same pattern as historical quantities (Wei, Xue, Yin & Ni , 2013).

Another method is the factor model, which uses factors such as total population, GDP, consumer price index and household size (Dyson & Chang, 2005; Wei, Xue, Yin & Ni , 2013). This method is more reliable and more common than the time-serious method, especially for long-term forecasts. However, with this model it is difficult to establish which factor has an absolute correlation with the generation quantities as well as the exact mathematical correlation. Furthermore, the selected factors need to be known before forecasting of waste generation can be done (Wei, Xue, Yin & Ni , 2013). With these limitations, system dynamics modelling was the preferred method for this study because it allows to capture the dynamic behaviour that relates to waste management.

System dynamics provides a set of conceptual tools concerned with the behaviour and structure of complex systems and is aimed at solving important and dynamic real world problems over time (Sterman, 2000). System dynamics modelling has been successfully applied in strategic and operational decision making in businesses (Maani & Cavana,

2007) and addressing major problems associated with assessing future scenarios (Kollikkathara, Feng & Yu, 2010), which the linear and static methods lack.

System dynamics can be used in two ways (Coyle, 1996). It can be used *qualitatively* to portray conceptual models as an aid to thinking and understanding. The conceptual models can then be turned into a mathematical model for *quantitative* simulation and optimisation to support policy design (Coyle, 1996). Various authors have indicated various phases to be followed in system dynamics, ranging from three (e.g. Wolstenholme, 1990) to eight (e.g. Richardson and Pugh, 1981) phases, as shown in Table 2.6.

Table 2.6: System dynamics modelling process across the typical literature

Randers (1980)	**Richardson and Pugh (1981)**	**Roberts et al. (1983)**	**Wolstenholme (1990)**	**Sterman (2000)**
Conceptualisation	Problem definition	Problem definition	Diagram construction and analysis	Problem articulation
	System conceptualisation	System conceptualisation		Dynamic hypothesis
Formulation	Model formulation	Model representation	Simulation phase (Stage 1)	Formulation
Testing	Analysis of model behaviour	Model behaviour		Testing
	Model evaluation	Model evaluation		
Implementation	Policy analysis	Policy analysis and model use	Simulation phase (Stage 2)	Policy formulation and evaluation
	Model use			

Source: Luna-Reyes and Andersen (2003)

Following Sterman's (2000) modelling phases, Step 1 recognises the problem to be addressed and asks the question ‘Who cares and why?’; Step 2 formulates a dynamic hypothesis about the cause of the problem, often using ‘causal loop diagrams’ or a ‘stock and flow’ map; Step 3 entails quantitative analysis and formulates a simulation model to test the dynamic hypothesis and is ultimately the most important stage in understanding the problem better; Step 4 involves testing the model until satisfied with its suitability for the purpose; and Step 5 formulates and evaluates policies for improvement based on the quantitative analysis. The different steps entail feedback processes and go through continuous iteration of questioning, testing and revision (Sterman, 2000).

According to Coyle (1996), it is sometimes practical to achieve desired understanding during qualitative analysis (steps 1 and 2) and therefore there is no need to continue with steps 3, 4 and 5. However, Coyle (1996) suggests that if qualitative analysis does not produce enough insight into the problem at hand, it is essential to proceed with a simulation model. Sterman (2000:37) is however of a different view and states that simulation is essential, arguing that …

> … most problem structuring methods yield qualitative models showing causal relationships but omitting the parameters, functional forms, external inputs, and initial conditions needed to fully specify and test the model. Regardless of the form of the model or technique used, the result of the elicitation and mapping process is never more than a set of causal attributions, initial hypotheses about the structure of a system, which must then be tested.

Davies, Musango and Brent (2016) are of a similar view to that of Sterman (2000), but argue for the use of qualitative analysis in situations where it is difficult and sometimes unattainable to quantify large numbers of soft variables.

System dynamics modelling is a powerful method to address the structural and dynamic complexity associated with waste management, as it accounts for feedbacks, accumulations, delays and non-linearities within a system (Escalante, 2012). Especially because system dynamics enables the representation of human agency and decision making in complex systems, its use in waste management planning can allow making the jump from the evaluation of normative statements (i.e. optimal strategies) to the testing of the viability and likelihood of policy implementation (Escalante, 2012).

Waste management systems over a long period, as was the case in this study, could shift due to a possible change in collection methods. System dynamics therefore offers interesting modelling approaches, as it can model the dynamic behaviour of waste and its various processes and actors over time (Inghels & Dullaert, 2010). System dynamics has been used widely in the waste management field. Table 2.7 provides a synopsis of various studies that have utilised system dynamics and the key aspects addressed in each study.

Table 2.7: Various applications of system dynamics modelling in waste management

Description	Key aspects	Reference
System dynamics modelling of urban solid waste management system	Developed a theoretical framework to examine urban solid waste generation and its management system in Dhaka city	Sufian and Bala (2007)
Evaluation of municipal solid waste generation, landfill capacity and related cost management issues	Developed a system dynamics model for municipal solid waste management, which consisted of a landfill module, a separate collection sector and the cost of policy options	Kollikkathara et al. (2010)
Application of system dynamics and fuzzy logic to forecasting of municipal solid waste	Examined factors such as environmental behaviour, recycling, treatment price, collected waste and regulation	Karavezyris, Timpe and Marzi (2002)
Forecasting of municipal solid waste generation in a fast-growing urban region with system dynamics modelling	Examined the driving factors in a generation/service centre, which include total income per service area, people per household, historical amounts of waste generated and population	Dyson and Chang (2005)
A system dynamics modelling of municipal solid waste management systems in Delhi	A system dynamics model for the existing municipal solid waste management system and for the proposed solid waste management system	Ahmad (2012)
Systems approaches to integrated solid waste management in developing countries	A review that demonstrates the importance of founding new solid waste management approaches for developing country contexts in post-normal science and complex adaptive system thinking.	Marshall and Farahbakhsh (2013)

Description	Key aspects	Reference
Application of system dynamics for municipal waste management in China: a case study of Beijing	System analysis that included a waste discharge system, waste administration system and waste disposal system	Lin and Ying (2013)
Sustainable waste management systems	Highlights the following: waste management as a complex system, the complexity of waste management, elements of a sustainable waste management system, implementing a systems approach to waste management, an integrated approach to waste management systems and sustainable societies	Seadon (2010)

Source: Compiled by researcher

Causal loop diagrams are the most commonly utilised tool for qualitative system dynamics analysis and represents the feedback structure in a system. The building blocks of causal loop diagrams are variables and arrows. The variables are often a condition, situation, decision or action that can influence and be influenced by other variables (Maani & Cavana, 2007). The arrows indicate the causal relationship between two variables and are shown with either a positive polarity, growth generating, or a negative polarity, goal seeking, and is shown as "+" or "-", respectively (Coyle, 1996; Maani & Cavana, 2007). Figure 2.8 illustrates a basic causal loop diagram of population dynamics.

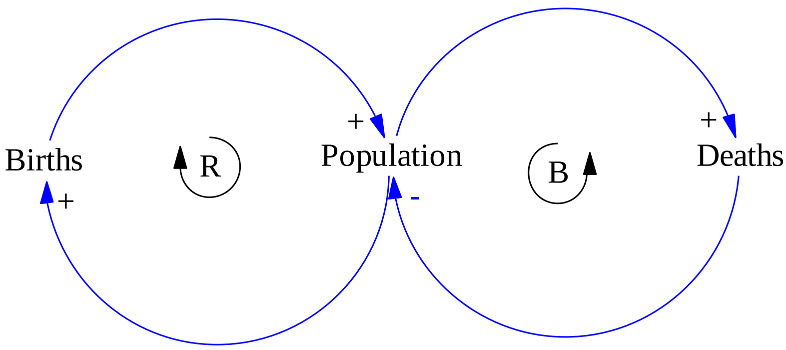


Figure 2.8: Example of a population causal loop diagram
Source: Adapted from Maani and Cavana (2007)

The causal loop diagram also shows the polarity link. If an increase (decrease) in one variable causes an increase (decrease) in the other variable, the polarity link is "+" because they move in the same direction of change, as illustrated by the polarity link between population and births in Figure 2.8. If an increase (decrease) in one variable results in a decrease (increase) in another variable, then the polarity link is "-" because they move in the opposite direction of change, as illustrated by the polarity link between deaths and population in Figure 2.8. Further, the two types of feedback loops, either a reinforcing loop, symbolised by "R" or "+", or a balancing loop, symbolised by "B" or "-", are also indicated in a causal loop diagram, as illustrated in Figure 2.8.

2.8 Summary

This chapter discussed the importance of recognising the problem of waste at both a global and a local scale, contextualised in both developed and developing countries. The undesirable consequences of traditional waste management practices fail to tap into the resource value of waste. Instead, ISWM practices are necessary. The waste management hierarchy was described as part of this approach. Some countries have made significant strides towards achieving ISWM practices by ‘closing the loop’ and using waste as a resource in order to safeguard the environment for future generations. A review of various methods in modelling future waste flows was undertaken and the utilisation of system dynamics, by means of a causal loop diagram, was argued for as an essential step in planning a waste management system.

The next chapter explains the research methodology utilised in this study.

Chapter 3: Research design and methodology

3.1 Introduction

The key objective of this study was to explore the dynamic factors influencing future domestic flows in the City of Cape Town. By understanding these factors, drivers of waste flows and solid waste management practices in developed and developing countries were examined. This chapter describes the research design, methodology and methods applied to answer the research problem and objectives.

3.2 Research design

According to Mahammad and Jalil (2013:6), research design refers to the "logical structure of inquiry. It articulates what data is required, from whom, and how it is going to answer the research question". Furthermore, Bryman and Bell (2014:80) state that a research design "provides a framework for the collection and analysis of data" and further state that "a choice of research design reflects decisions about the priority being given to a range of dimensions of the research process".

Bryman and Bell (2014) outline five different research designs, namely i) experimental design, ii) cross-sectional design, iii) longitudinal design, iv) case study design and v) comparative design. This leads to the question of what information needs to be collected to answer the research problem, which ultimately leads to the choice of methods and may include whether qualitative or quantitative data are required, or a mix of the two methods.

The choice of research design and methods was guided by the specific research objectives. This study utilised a case study design and qualitative research strategies. Case study design is an in-depth study of one or more cases and is concerned with the complexity and particular nature of the case (Bryman & Bell, 2014). Therefore, case study design was deemed suitable to this study, as it focused on solid waste management practices in the City of Cape Town. Qualitative research strategies, which ask 'why' and 'for what reason' something occurs, were employed to obtain quality data (cf. Bryman & Bell, 2014).

Figure 3.1 depicts the research design followed to consider the research problem and the research objectives.

The objectives of this study were to:

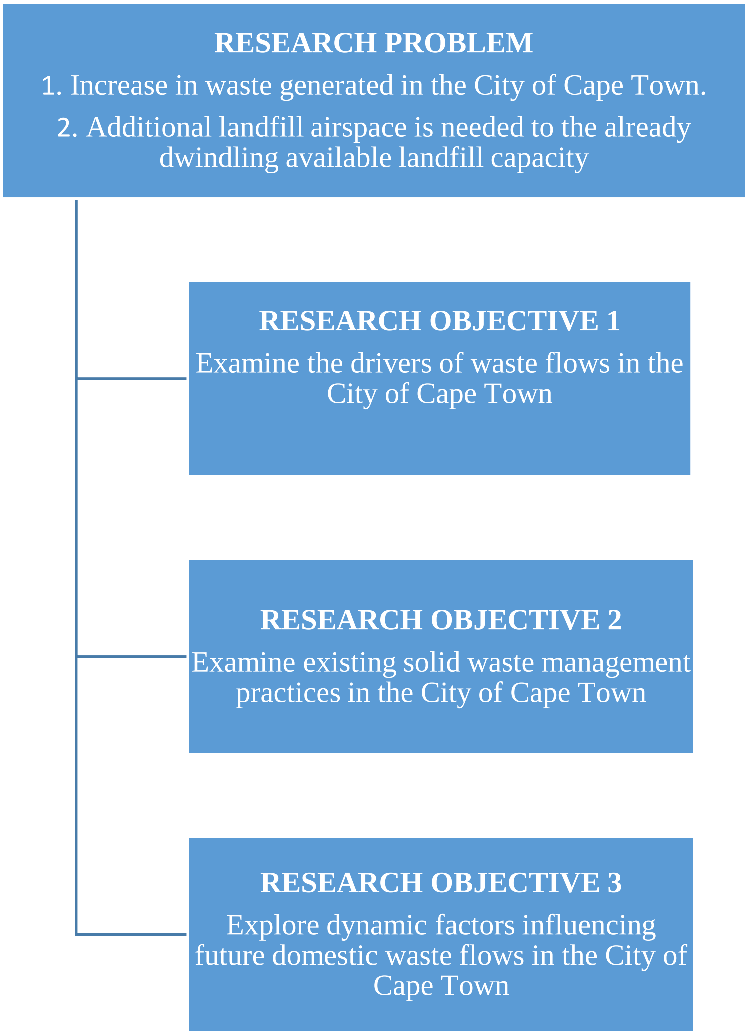


Figure 3.1: Research strategy
Source: Compiled by researcher

3.3 Research methodology

Research methods are techniques for collecting data (Bryman & Bell, 2014). Different data-collection methods exist, such as i) sampling, ii) surveys and questionnaires, iii) interviews and focus group discussions, iv) fieldwork, v) data gathering for secondary analysis, vi) internet research and vii) content analysis (Bryman & Bell, 2014).

Secondary analysis, using documents as sources of data, was chosen as the preferred method to collect data, as it not only saves cost and time, but also provides high-quality data and more time for analysing data, such as public documents published by the organisation in question (Bryman & Bell, 2014). The City of Cape Town, a local government institution, provided a great deal of information for this study. All relevant information, such as annual reports, external consultancy reports, theses and policy statements, was obtained either via internet research or from the City of Cape Town's website (www.capetown.gov.za).

3.4 Research method

This section discusses the research methods and techniques applied in order to answer the three research objectives. Various information techniques and tools were specific to each research objective.

3.4.1 Research objective 1: Examine the drivers of waste flows in the City of Cape Town

In order to achieve this objective, it was necessary to conduct a comprehensive literature review, which provided insight into current key trends of waste flows in a global context. As informed by the literature in Section 2.5, waste generation is generally categorised into three groups, namely i) economic drivers, ii) socio-economic drivers and iii) political drivers. These were therefore examined with reference to the City of Cape Town. Secondary information was mainly utilised in examining these three categories of waste generation in the context of the City of Cape Town due to the limited information available on the City of Cape Town in peer-reviewed literature

Having established the three key waste flows drivers for the City of Cape Town, it was deemed important to understand the state of solid waste management through the

ISWM framework of three physical systems and three governance aspects. This was achieved in the second research objective.

3.4.2 Research objective 2: Examine existing solid waste management practices in the City of Cape Town

The literature review conducted provided insight into historical and current waste management practices in a global context. It was evident from the literature that significant strides have been made globally to move from traditional waste management practices towards ISWM that includes all the elements of the internationally adopted waste management hierarchy. These were discussed in Section 2.4.3.

The ‘two triangles’ analytical framework for solid waste management in the world’s cities (Wilson et al., 2013), shown in Figure 2.9, was used to examine the existing trends and realities in the City of Cape Town. This framework has been used widely and shows good work being done on solid waste by cities around the world, including large and small, rich and poor cities. It examines what drives change in solid waste management, how cities find local solutions and what seems to work best under different circumstances (Wilson et al., 2013).

The physical elements of a solid waste management system are linked to public health, waste resource management and environmental protection in order to address waste management for an ISWM system to work sustainably in the long term. The governance aspects entail inclusivity, sound institutions and proactive policies, and financial sustainability, to be addressed to deliver a well-functioning system (Wilson et al., 2013).

A basic instrument by means of a set of indicators, in relation to the drivers, was adopted and used, as drawn from the City of Cape Town’s grey literature. A profile of the City of Cape Town’s solid waste was examined against indicators, as outlined in Table 3.1. An indicator shows how the City of Cape Town has addressed one of the drivers. It should be noted that integrated solid waste management is a process and that the indicators only reflect a snapshot in time (Wilson et al., 2013).

Table 3.1: Overview of indicators

Physical elements		
Indicator name	***Indicator***	***Driver***
Collection	The percentage of households that have access to waste collection services	**Public health** Involves keeping waste and associated vectors from waste accumulating in the city
Controlled disposal	The percentage of waste that is being landfilled with basic controls or any treatment system	**Public health in combination with environmental protection** Involves the controlled disposal of waste that ends up at landfill. Where waste is managed through modernisation, the protection of site staff and the prevention of water, soil and air pollution is well managed **Environmental protection** Proportion of waste that enters the waste system and is further processed Illegal dumping of waste in open spaces and watercourses
Resource management	The percentage of waste collected by the formal and informal sector or disposed of by households at drop-off facilities The percentage of waste that is prevented and recovered before disposal due to valorisation	**Recovery percentage or recycling rate**

Governance aspects		
Indicator name	***Indicator***	***Driver***
Inclusivity	The degree of user and provider inclusivity in policy formation, planning, implementation and evaluation of these services	**User inclusivity:** The degree to which stakeholders are included in the planning, policy formation and implementation process System performance and the extent to which it serves all users equitably and according to their needs and preferences **Provider inclusivity**: The extent to which the economic niches and service delivery and valorisation are open and accessible to non-state actors, the private and informal sectors and community based-organisations The degree to which the authority allows and enables non-state providers to be integrated within the overall solid waste collection, transfer, materials recovery and disposal strategy
Financial sustainability	The percentage of households that use and pay for waste collection services	Population using and paying for collection as percentage of total population and subsidised systems
Institutional coherence	The ability of the local governing entity to control the overall budget for solid waste management	The extent to which the institution rests on sound institutions and proactive policies

Source: Adapted from UN-Habitat (2010)

3.4.3 Research objective 3: Explore dynamic factors influencing future domestic waste flows in the City of Cape Town

An analysis of system dynamics was conducted, as described in Section 2.7, with a specific focus on qualitative analysis using causal loop diagrams. The third research objective entailed developing a causal loop diagram to explore the dynamic factors influencing future domestic waste flows in the City of Cape Town. The different factors were identified in objectives 1 and 2. The causal loop diagrams were drawn using Vensim® software.

3.5 Summary

This chapter presented the research methodology utilised in the study. The literature review was utilised to achieve objectives 1 and 2. Objective 3 was achieved using qualitative system dynamics, mainly causal loop diagrams, to provide insights into the dynamic factors influencing waste flows in Cape Town. Chapter 4 presents the results of the study.

Chapter 4: Results

4.1 Introduction

This chapter presents the results of this study. The first section discusses the drivers of waste flows in the City of Cape Town. The second section discusses solid waste management practices in the City of Cape Town, while the third section discusses factors influencing future domestic waste flows in the City of Cape Town.

The City of Cape Town, a metropolitan municipality, is situated in the southern peninsula of the Western Cape province of South Africa (Figure 4.1) and covers an area of approximately 2,445 km^2. It is the economic hub and capital of the province as well as the legislative capital of South Africa.

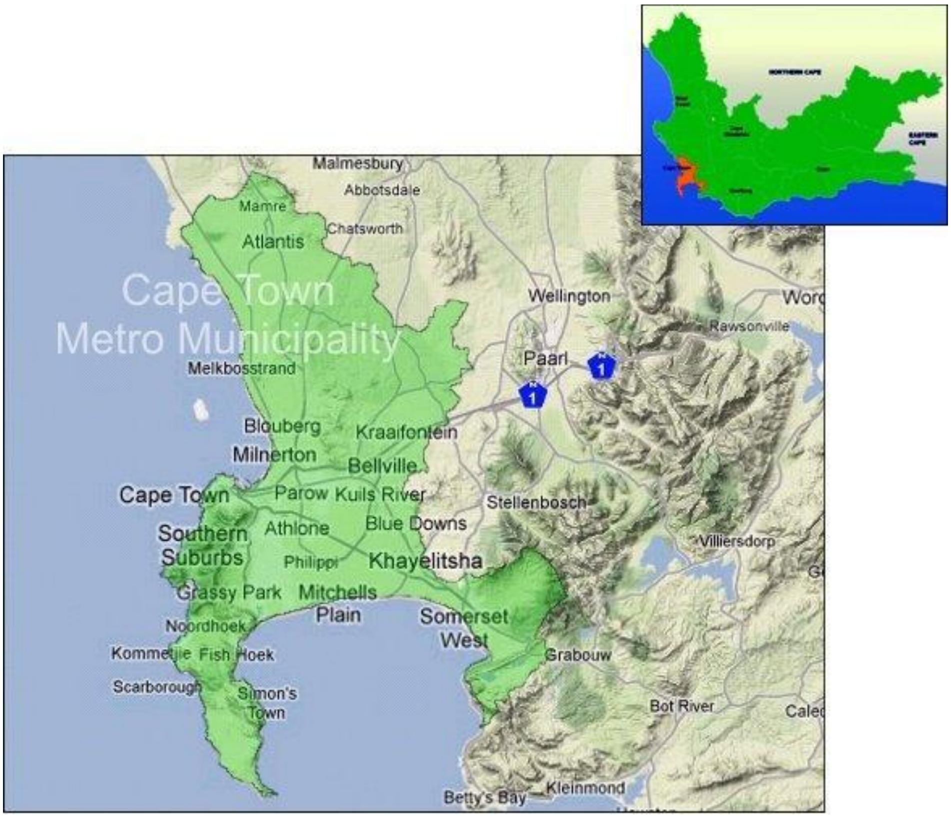


Figure 4.1: City of Cape Town metropolitan municipality
Source: www.capetown.gov.za

The City of Cape Town is divided into four solid waste management districts, namely Impuma (615 km^2), Tierberg (654 km^2), Atlantic (726 km^2) and Two Oceans (479 km^2) (Engledow, 2007). Each of these management districts are representative of a mix of income suburbs (affluent communities to informal settlements) (Engledow, 2007).

4.2 Drivers of waste flows in the City of Cape Town

The identified three drivers of waste generation were broadly categorised into economic drivers, socio-economic drivers and political drivers. From this, indicators were identified that relate to each driver that are specifically relevant to the City of Cape Town. The indicators for economic drivers were income (GDP) and employment, the indicators for socio-economic drivers were population and household size, and the indicators for political drivers were various legislation, ranging from national policies to local government policies and by-laws. Each of these broad drivers with reference to the City of Cape Town is discussed in the sections that follows.

4.2.1 Economic drivers of waste flows in the City of Cape Town

The literature review indicated a strong relationship between contributing factors of waste generation such as GDP, private consumption, economic activity, household income, improved living standards, employment and changing lifestyle (Dyson & Chang, 2005; OECD, 2002; Wei et al., 2013). The indicators that relate to economic drivers and relevant to the City of Cape Town are discussed below.

i. GDP

Cape Town is a fast-growing, emerging city and is one of the largest receivers of South African and international migrants. It is estimated that 40% of the population growth in Cape Town between 2001 and 2011 was from new arrivals from outside the Western Cape. The GDP per capita and GDP per capita growth rates for Cape Town and South Africa (2004–2014) are shown in Figure 4.2.

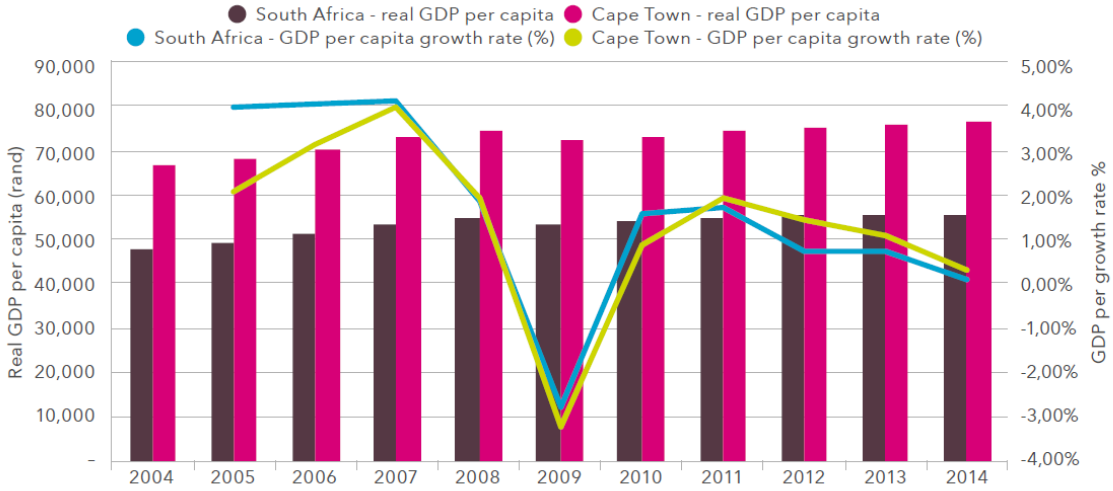


Figure 4.2: GDP and real GDP – South Africa and Cape Town for 2004–2014

Source: City of Cape Town (2016b)

The positive growth in Cape Town's GDP is that of population growth and also increased productivity due to economies of scale and specialisation in the production of goods and services. The services economy (finance and insurance) dominates in Cape Town (City of Cape Town, 2016b).

ii. Employment

The majority of households (47%) fall in the low-income group (no income to R50 613 per annum), whereas a substantial amount of households (39%) fall in the middle-income group (R50 614 to R404 901 per annum), with only 14% of households falling in the high-income group (R404 902 to R3 239 207 or more per annum). These figures indicate that Cape Town is a middle-income municipality.

The unemployment rate in Cape Town increased from 19,2% to 22,1% between 2008 and 2015 and was attributed to the 2008 economic downturn. The unemployment rate decreased from 24,9% in 2012 to 22,1 in 2015 (City of Cape Town, 2016b). The indigent households (people who are not in a position to pay for basic services such as waste collection) in the City of Cape Town are shown in Figure 4.3. The figure indicates that poverty is still widespread in the City of Cape Town. The annual household numbers show decreases and increases from the 2003 historical baseline figure, hence there is no real trend.

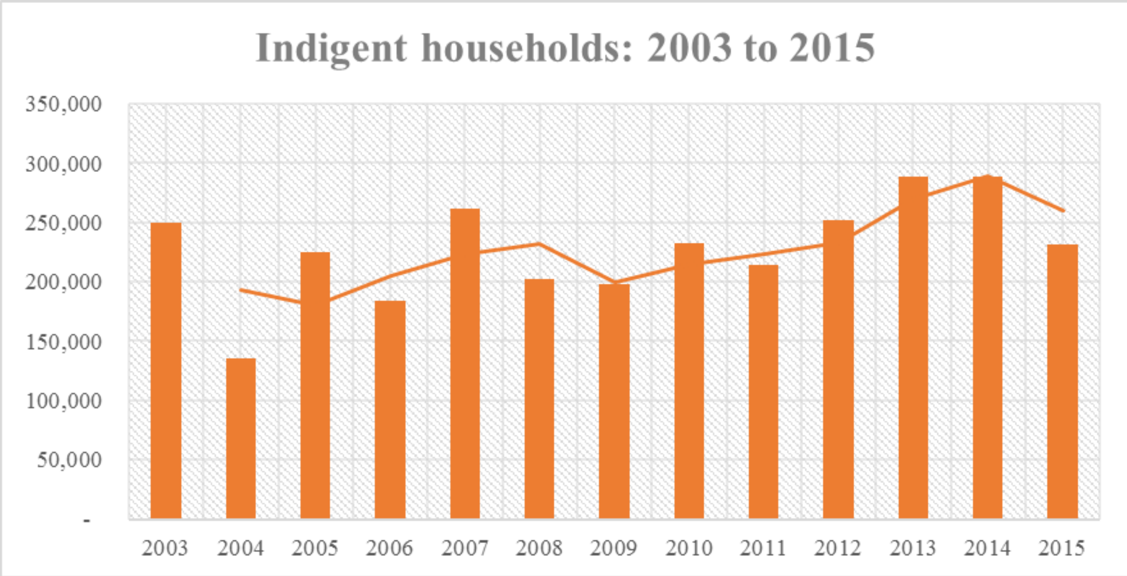


Figure 4.3: Indigent households for 2003 to 2015
Source: City of Cape Town (2016b)

As economic development and population dynamics have a major impact on municipal waste generation in the City of Cape Town, an assessment of socio-economic drivers of waste generation indicated that for every 1% of GDP growth/annum, the amount of waste that is being landfilled increases by 0,6% and the amount of waste collected increases by 0,42%, and a 1% growth in population has led to a 0,9% change in waste being disposed of at landfill (City of Cape Town, 2016a).

4.2.2 Socio-economic drivers of waste flows in the City of Cape Town

The literature reviewed indicated a strong relationship between contributing factors of waste generation such as urban population, population growth and people per household (Dyson & Chang, 2005; Lea et al., 2004; Mazzanti & Zoboli, 2008; Oyoo et al., 2011). The following indicators relate to socio-economic drivers and are relevant to the City of Cape Town:

i. Population

Cape Town is still growing, with 2014 population figures estimated at 3 882 662 people. Cape Town is ranked the 10th most populous city in Africa and in 2016 the population was estimated at 4 004 793 (City of Cape Town, 2016b). Between 1996 and 2011, the population grew from 2 563 095 to 3 740 026, resulting in a positive growth of 45,9% (City of Cape Town, 2016b; 2017). A 10-year trend migration analysis (2001–

2011) indicated that the majority of in-migration came from outside the Western Cape (City of Cape Town, 2014).

Statistical figures on demographic trends in the City of Cape Town indicate that the population will increase over the next 20 years and is expected to grow to 4,2 million and 4,46 million by 2022 and 2032, respectively (City of Cape Town, 2016b), with a continuous influx of people from neighbouring provinces and countries. This positive growth in population results in an increase in waste generation, which is associated with an increased demand for waste collection services and landfill airspace.

ii. Household size

The number of households in Cape Town increased from 653 085 in 1996 to 777 389 in 2001. In 2011, the households increased to 1 068 572. This represents an increase in households of 63,6% since 2001 and indicates a positive growth in households for the respective periods. Apart from the growth in households, there seems to be a trend towards smaller household units across all population groups with an estimated 0,6 million more households between 2011 and 2035 (1,7 million – average of three members).

The average household members is less than in developing countries (five members) and is moving closer to that of developed countries (two to three members). This means an average household size of three members. This results in an increasing demand for housing supply (City of Cape Town, 2016b), which relates to a greater demand for waste collection infrastructure, as smaller households mean more dwellings over greater waste collection areas, additional collection infrastructure and additional landfill airspace.

Waste generation in 2007 reached a high of approximately 730 kg/person/annum. This figure includes domestic and the majority of waste from commerce and industry (City of Cape Town, 2016b). For the period 2007–2015, the waste generation showed a gradual increase with an estimated growth of 2,6%, which accounted for migration as well. The average waste generation rate per person was estimated to be 580 kg/person/annum (City of Cape Town, 2017). This showed a decline from the 2007 waste generation figures.

4.2.3 Political drivers of waste flows in the City of Cape Town

The literature review indicated that political drivers are specific legislation that promotes waste prevention, source separation and landfill diversion policies, with the latter being most dominant in the waste management field (Mazzanti & Zoboli, 2008). The following indicators relate to political drivers and are relevant to the City of Cape Town:

- Waste management in South Africa, a developing country, is also underpinned by the internationally accepted waste management hierarchy, which illustrates that waste avoidance and reduction is the most desired state for a sustainable waste management system, with the least desired being waste treatment and disposal to landfill. This waste management hierarchy is the primary building block of an ISWM framework to deliver services for residents and businesses in a municipality.

- South African municipalities are required by the National Environmental Management: Waste Act, No. 59 of 2008 to adopt an integrated waste management approach when dealing with waste. Incremental changes to how waste has been handled in the past have been implemented by some municipalities. The most obvious is where municipalities start with recycling initiatives with the aim to reduce the negative impacts of waste disposal on the environment and people's health.

- The National Waste Management Strategy of 2011 is a legislative requirement of the National Environmental Management: Waste Act, No. 59 of 2008 and is structured around a framework of eight goals, which were to be met by 2016 (DEA, 2011). Of relevance for this study is Goal 1: Promote waste minimisation and the reuse, recycling and recovery of waste. Goal 1 stated that at least 25% of recyclables needs to be diverted from landfill sites for reuse, recycling or recovery by 2015 and that all metropolitan municipalities initiate source separation programmes by 2015 (DEA, 2011).

The City of Cape Town has adopted the objects of the National Waste Management Strategy of 2011 in The City of Cape Town Integrated Waste Management (IWM)

Policy (2009). The city became the first municipality in South Africa to introduce a by-law that regulates and enforces integrated waste management in its area of jurisdiction (City of Cape Town, 2014). This policy is aligned with national legislation and was adopted by Council and promulgated on 21 August 2009 (City of Cape Town, 2013).

The policy contains principles, levels of service for various socio-income groups, based on the municipality's geography and accessibility, and standards for waste management. The overarching objectives of the policy is to provide waste management services to all communities, reduce the amount of waste to landfill facilities and prevent the degradation of the environment and the impact on human health (City of Cape Town, 2013).

The City of Cape Town has an Integrated Waste Management By-law that was promulgated in June 2010. The by-law enforces the objectives of the Integrated Waste Management Policy (City of Cape Town, 2013) and aims at regulating and controlling solid waste management in the municipality to ensure a uniform approach to waste management.

Before the passing of the Waste Act, the City of Cape Town started addressing the challenges of sustainable waste management practices by enforcing reduction measures due to the pressing need for available landfill airspace (Swilling & Annecke, 2012). The City of Cape Town's Solid Waste Management Department is one of the very few municipalities in South Africa, from a sustainability perspective, with the commitment to include a green urbanism agenda to create more sustainable places and lifestyles and where consumption of the world's resources are less (Swilling & Annecke, 2012).

4.3 Solid waste management practices in the City of Cape Town

The 'two triangles' analytical framework for solid waste management in the world's cities was used to examine the existing management practices and realities in the City of Cape Town. The framework is divided into two system elements, namely i) a physical component, which is linked to three drivers (public health, waste resource management and environmental protection) to enable an ISWM system to work sustainably over the long term, and ii) governance aspects (inclusivity, sound institutions and proactive policies, financial sustainability) that need to be addressed to deliver a well-functioning solid waste management system (Wilson et al., 2013). Information on governance aspects in the City of Cape Town is included throughout the results and not under a separate heading, as governance is considered in collection type and systems, disposal and resource management.

4.3.1 Main driver for municipal solid waste management in the City of Cape Town

Municipal solid waste management poses pressures to municipalities and cities and there is no single solution, as drivers behind municipal solid waste management vary significantly from city to city. In the context of the City of Cape Town, resource management was the main driver since 2006, when recycling was considered as a strategic means of diverting waste from landfill (City of Cape Town, 2014) in order to increase the existing landfill capacity. It is also during this period that reporting on waste information began and was made available.

During the financial years 2013/2014, 2014/2015 and 2015/2016, at least 7,61%, 9,15% and 20,58%, respectively, of waste by mass was diverted from landfill sites (City of Cape Town, 2016b; 2017). This indicates a positive trend in waste minimisation efforts by the City of Cape Town (City of Cape Town, 2016b; 2017), but excludes private sector waste minimisation initiatives, as reporting from this sector is poor, with few companies having waste management plans in place.

Oelofse and Godfrey (2009) state that waste generation rates differ noticeably across income groups. Dating back to 1998, domestic waste in the City of Cape Town constituted 895 000 tons with at least 492 967 tons generated from high-income areas. This is broken down into 1,3 kg/capita/day in high-income areas, 0,7 kg/capita/day in middle-income areas and 0,35 kg/capita/day in low-income areas (Swilling, 2006). According to Swilling and Annecke (2012), the 2007/08 average per capita rate (kg/capita/day) in the City of Cape Town was 2 kg. At a national level, in South Africa, low-, middle- and high-income areas generated 0,41, 0,71 and 1,29 kg/capita/day, respectively (Oelofse & Godfrey, 2009).

Cape Town's waste generation, which is higher than the national high-income areas is possibly because Cape Town is a middle income city and approximately 50% of household's waste is generated by the high income households (Swilling & Annecke, 2012).

In the City of Cape Town, during the period 1998–2009, changes in the waste generation rates were minuscule; however, the total waste quantities increased as the population increased. This can be translated that people had not changed their consumption patterns during this time.

4.3.2 Waste collection practices in the City of Cape Town

The regulator and authority of municipal waste management services in the City of Cape Town is the Solid Waste Management Department. This department consists of various branches, namely Waste Minimisation; Research and Development; Planning; Collections and Waste Disposal Activities.

In 2011, approximately 94% of the 1 068 572 households in the city received weekly domestic waste collection services (Western Cape Government Provincial Treasury, 2014). The households were divided into formal households (837 533), informal dwellings (shack in backyard) (74 958) and shacks (not in backyards) (14%). With the increase in population (3 740 025 in 2011 to 3 882 662 in 2014), the service levels remained at least constant (PwC, 2014). In 2016, the majority of households, at least 92,3%, received a weekly refuse collection service (City of Cape Town, 2016b).

The City of Cape Town, with private sector participation, renders a refuse collection service to formal and informal households as well as backyard dwellers residing on Council rental stock land and on formal private properties operated by the municipality and service providers. In 2017, 100% of formal households are provided with a weekly kerbside wheelie bin refuse collection service. Informal households in informal settlements are provided with a weekly door-to-door plastic bag refuse collection service or ongoing litter picking.

The municipality also collects illegal dumping in informal areas. The plastic bags are taken to shipping containers, where they are stored and later transported to the nearest landfill site. The shipping containers are serviced twice a week. Backyard dwellers residing on Council rental stock land receive a formal weekly wheelie bin kerbside refuse collection service, whereas a pilot project to roll out wheelie bins to backyard dwellers living on formal private properties are underway (City of Cape Town, 2016b; 2017).

The waste composition in the City of Cape Town is depicted in Figure 4.4. It is noted that domestic waste is the largest single municipal waste stream in the City of Cape Town. A breakdown of domestic waste, surveyed in 2011, is shown in

Figure 4.5. The major fractions of waste in the domestic waste stream are paper (15,50%), followed by garden waste (15.20%), with e-waste at 5.50% (City of Cape Town, 2013).

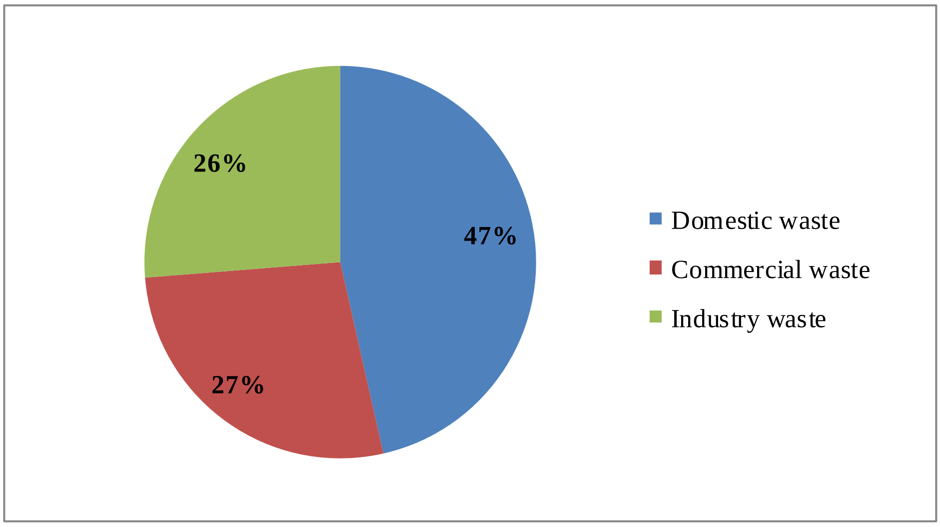


Figure 4.4: Composition of municipal solid waste in the City of Cape Town
Source: City of Cape Town (2013)

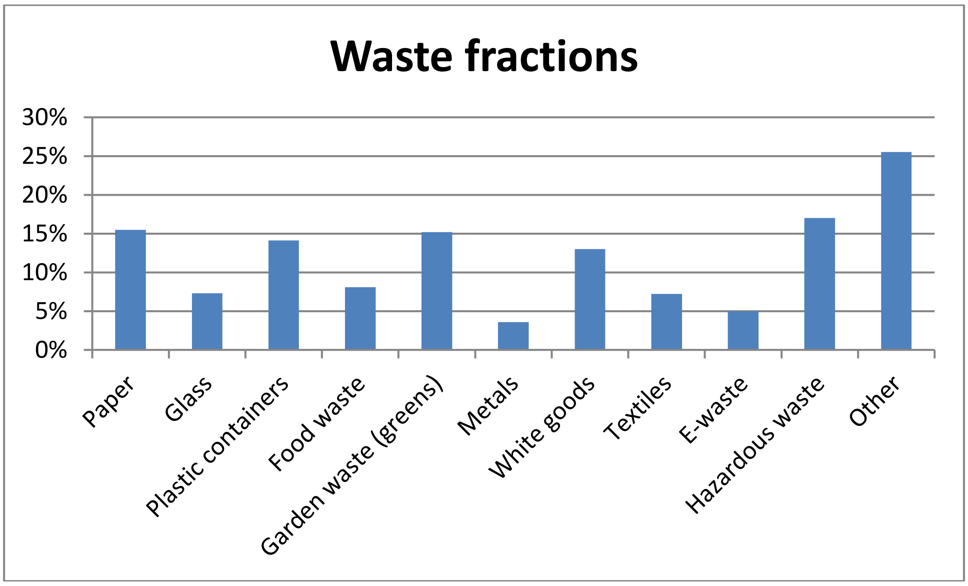
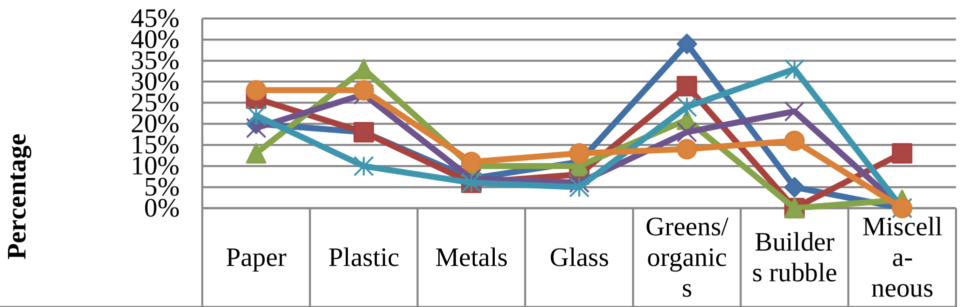


Figure 4.5: Composition of domestic waste streams
Source: City of Cape Town (2013)

Furthermore, a waste characterisation survey conducted by the Western Cape Government in 2007 (Figure 4.6) revealed that the dominant waste stream is greens and organics (39%) followed by paper. It is uncertain whether this study wholly focused on the domestic waste stream, as there is a notable difference in the composition between this study and the domestic waste stream survey of 2011 in

Figure 4.5. The researcher believes
Figure 4.5 to be more reliable, as the figure is captioned "Composition of domestic waste streams".



	Paper	Plastic	Metals	Glass	Greens/ organics	Builders rubble	Miscell a- neous
City of Cape Town	20%	18%	7%	11%	39%	5%	0%
Cape Winelands	26%	18%	6%	8%	29%	0%	13%
Eden	13%	33%	10%	10%	21%	0%	2%
West Coast	19%	27%	7%	6%	18%	23%	0%
Overberg	22%	10%	6%	5%	24%	33%	0%
Central Karoo	28%	28%	11%	13%	14%	16%	0%

Figure 4.6: Waste characterisation survey: Western Cape municipalities
Source: Western Cape Government (2013)

The City of Cape Town's ability to generate income and recover costs is directly influenced by its stakeholders' ability and willingness to pay for rates and tariffs (City of Cape Town, 2017). The municipality has an indigent fund that caters for indigent households unable to pay for waste collection fees. The municipality has a prerogative regarding choice of service mechanisms and service provision as well as tariff setting to its residents. There are different rates for residential collections depending on the value of the residential property.

4.3.3 Waste disposal practices in the City of Cape Town

Waste disposal data are available from 2006, when consolidated reporting began. The City of Cape Town reached a maximum disposal rate of 2 500 000 tons of waste in 2007. This waste includes household, commercial and industry waste. There has been a sharp decline between 2008 and 2009, which could be attributed to the global economic downturn, and the figure has increased significantly since.

During the years 2013/2014, 2014/2015 and 2015/2016 at least 2,39 million, 2,51 million and 2,44 million tonnes of waste, respectively, was disposed of at the landfill sites (City of Cape Town, 2017). There is no real trend during the three years given the high waste minimisation achieved in 2015 (reported earlier in Section 4.3.1).

The main method currently used to manage solid waste is disposal at landfills. There are only three operating landfills in the City. These are Bellville South, Coastal Park and Vissershok, owned by the City of Cape Town, and one privately owned hazardous landfill site next to Vissershok (Engledow, 2007). The remaining lifespans of the three landfill sites owned by the city are all very limited, with 10 years' remaining airspace. The operating landfill sites cover an area of approximately 300 hectares of land.

The city owns two refuse transfer stations, the Athlone Refuse Transfer Station and the Swartklip Refuse Transfer Station. The Athlone Station includes a rudimentary 'dirty' Materials Recovery Facility. Waste from Athlone Station is compacted and sent via rail, whereas waste from the Swartklip Station is compacted and sent via refuse trucks to the Vissershok landfill site. A third refuse transfer station, Bellville Waste Management Facility, was constructed in 2015 and is not operational yet. This facility will replace the Bellville landfill site once closed.

The city also owns an IWM facility in Kraaifontein. The Bellville landfill site is due to close in September 2018. The Coastal Park landfill site has limited landfill airspace and will close in 2022. The Vissershok landfill site has 10 years of remaining airspace left. This site also receives low hazardous waste. Next to the Vissershok landfill site is the privately owned Vissershok Waste Management Facility, which receives high-rated hazardous waste.

An application to increase the capacity at the Vissershok landfill site commenced and is awaiting approval from the competent authority. The Visserhok North landfill site, which has not been developed yet, will assist in relieving pressure on existing landfill infrastructure. In 2000, the City of Cape Town commenced with the identification of a new regional landfill site to serve the municipality for another 30 years. A record of decisions was issued in 2013 in favour of a site near Kalbaskraal, north of Cape Town. However, an appeal from adjacent owners has been lodged against this site and is being addressed through a legal process (City of Cape Town, 2016b; 2017).

4.3.4 Waste resource management practices in the City of Cape Town

The City of Cape Town has a number of ongoing recycling activities to divert waste from landfill, such as a split bag pilot household recycling programme in Marina da Gama, which started in 2002 (Engledow, 2007) and was followed by the Think Twice separation at source initiative in 2006 in selected income areas across Cape Town.

The Think Twice separation at source initiative is outsourced on a three-year cycle to an external contractor who processes the dry recyclables at the Kraaifontein IWM facility, owned by the City of Cape Town. This project has been rolled out to 200 086 households. However, the project is constraint by budget to further roll-out to more households. Other waste minimisation measures are 24 public drop-off facilities, situated within a 7-km radius between one another, to which residents are encouraged to bring their recyclables, electronic waste, building rubble and garden waste. Not all residents own vehicles and this is only practical for households that own vehicles and live in close proximity to the facilities.

In 2016, a home composting project was initiated in which 5 500 bins were distributed to home owners across the municipality in an attempt to divert organic waste from landfill. The results from the separate green waste feasibility study in the 2012–2014 financial year indicated the potential of approximately 17 kg per household per month of organic waste being diverted from low- and middle-income areas in the City of Cape Town.

As the composting project is spread across the municipality, it is not possible to obtain the impact the diversion of organic waste may have on the collection costs for waste management. The organic waste diversion project is aligned to the national government's strategy, titled the National Organic Waste Composting Strategy: Draft Strategy Report, which aims to ensure, where viable, that organic waste is diverted from landfill sites as an alternative treatment through integrated and sustainable waste management planning (DEA, 2013).

4.3.5 Environmental protection in waste management practices in the City of Cape Town

The City of Cape Town landfill operating permits allow for biogas to be vented in a controlled manner. The municipality is exploring the feasibility of a landfill gas-to-electricity project in partnership with the Central Energy Fund at two of its operating landfill sites. This is an attempt to reduce greenhouse gases emitted into the atmosphere and to protect human health and the environment. This process will allow the municipality to be compliant with the Clean Development Mechanism projects that are registered in terms of the Kyoto Protocol and could generate additional income.

A project funded by the German Development Bank is examining the type of disposal and treatment technology that can be implemented in the municipality to reduce the amount of waste going to landfills. A transaction advisor was appointed to assess alternative service delivery mechanisms that are focused on the City of Cape Town's solid waste management system to incorporate large-scale waste minimisation. The feasibility assessment of all new projects may result in private sector involvement to develop these projects as part of the goal to build a green economy (City of Cape Town, 2016b; 2017).

Table 4.1 provides key benchmark numbers that are quantitative information provided by the City of Cape Town in the various secondary documents examined.

Table 4.1: Key benchmark numbers

Description	Benchmark	Description	Benchmark
Total tons of waste generated per annum	2,44 million in 2015/20160	Percentage waste volarised of the total waste generated	20,58% in 2015/2016
Generation per capita in kilograms per year	580 kg/capita/day	Percentage waste volarised by private sector of total municipal solid waste generated	No information available
Percentage waste collection coverage	92,3%	Waste collection goals as percentage of population	100%
Percentage disposal in controlled disposal sites of total waste generated	79,42%	Goals for environmentally safe disposal	Moratorium on regional landfill site
Percentage municipal waste incinerated/treated of total waste generated	0%	Goals for valorisation waste materials through diversion from disposal	Think Twice separation at source initiative is constraint by budget to further roll-out
Percentage diverted and valorised of total waste generated	Not available	Waste prevented, reused, recycled, composted	20,58% of municipal solid waste (recycled)

Source: Adapted from UN-Habitat (2010)

4.4 Factors influencing future domestic waste flows in the City of Cape Town

This section provides the results from the causal loop analysis on the key drivers that influence future waste flows. These were categorised into six main feedback loops that were identified based on the two triangles analytical framework, which are each discussed in the sections that follow.

4.4.1 Public health feedback loops: B1, B2 and B3

Issues relating to the public health driver consist of three feedback loops, B1, B2 and B3, as shown in

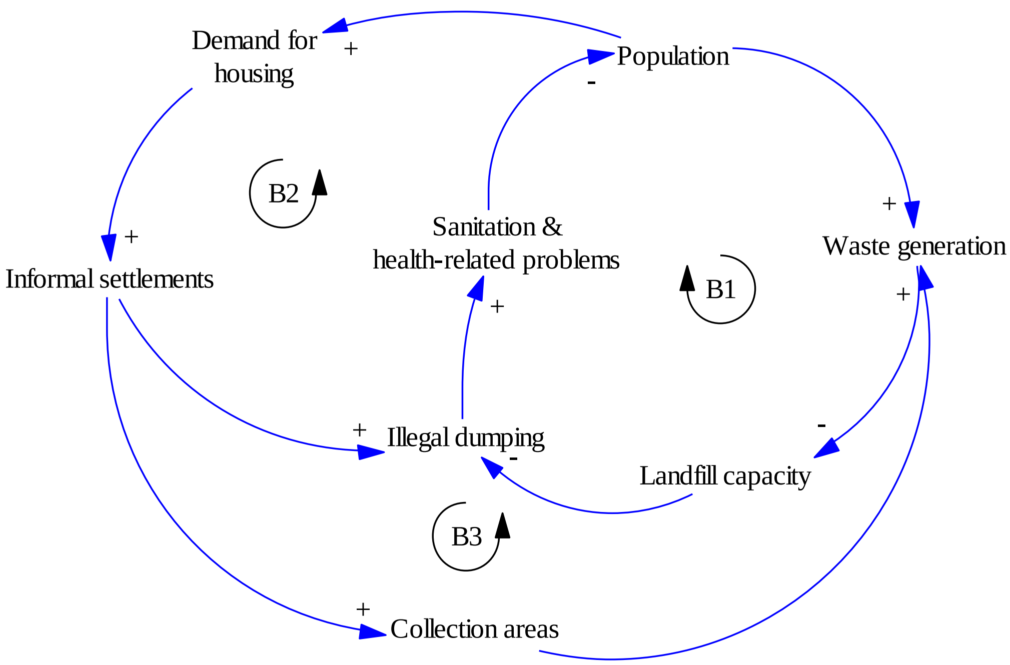


Figure 4.7. Population, one of the key drivers identified for waste generation, is the main variable in the two balancing loops associated with public health feedback in the City of Cape Town.

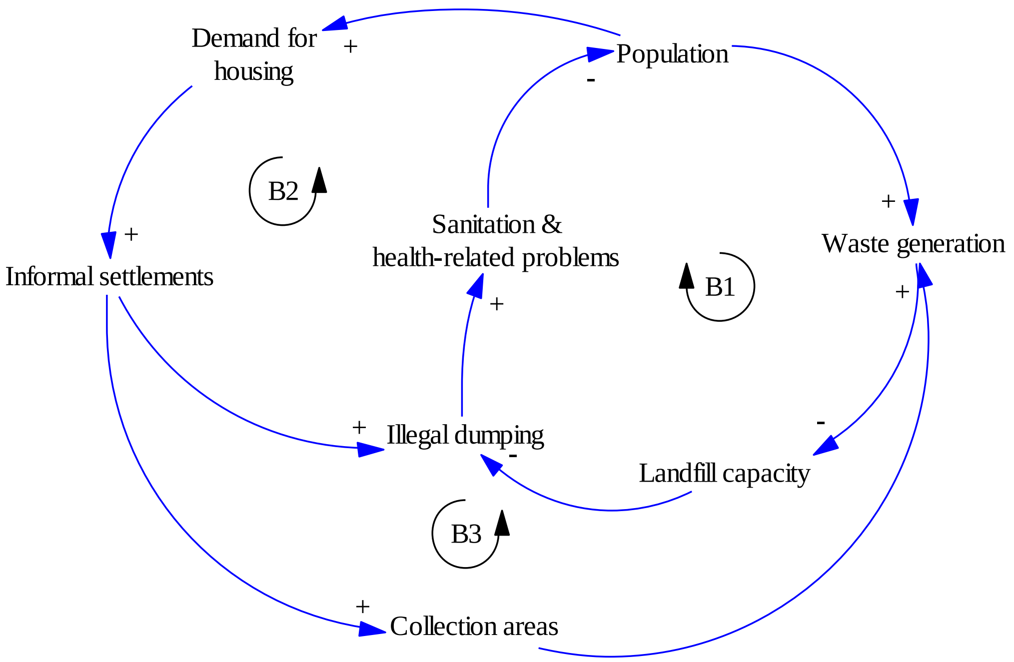


Figure 4.7: Public health feedback loops

Balancing loop 1 (B1) indicates that Cape Town has a growing population, resulting in an increase in waste generation, which further adds pressure to the already limited landfill airspace (City of Cape Town, 2016b; 2017). This results in illegal dumping and poor sanitation, especially in the low-income, densely populated areas. This impacts on the health of people, especially infants, and may ultimately lead to death. This leaves room for improvement in waste collection in informal areas, but also requires a shift in residents' behavioural problems, which is a complex challenge.

Balancing loop 2 (B2) also represents a growing population, which results in a demand for more housing and an increase in informal dwellings. As the City of Cape Town's household size is becoming more that of developed countries (from five members to two to three members) (City of Cape Town, 2016b), this may lead to greater collection areas over longer distances, but also further impacts landfill capacity.

In addition, Balancing loop 3 (B3) indicates that an increase in informal dwellings will enhance illegal dumping even more, thereby further impacting on people's health and sanitation. This will perpetuate the already existing illegal dumping problem identified in Balancing loop 1 (B2). The effects of poor management on human and environmental health, expounded in Section 2.6, cause offensive smells, blocks drains and causes flooding, which attracts vectors and rodents and subsequently leads to the spreading of waterborne diseases, which may lead to child diseases and mortality (City of Cape Town, 2016b).

In terms of the governance aspect regarding the *degree of user and provider inclusivity in policy formation, planning, implementation and evaluation of these services* and *financial sustainability*, the municipality has a by-law relating to illegal dumping and spends millions on clean-up efforts on illegally dumped waste despite remedial measures of continuous campaigns against illegal dumping, namely on social media, billboards, waste collection vehicles, etc. (City of Cape Town, 2016b; 2017). This is an indication that the municipality is self-supporting; however, these high costs could be spent elsewhere, for instance more houses and infrastructure could be established for those living in informal settlements (City of Cape Town, 2016b; 2017). A novel approach is necessary and the City of Cape Town can learn from the Curitiba case study mentioned in Section 2.4.1. The city of Curitiba was rewarded with a United Nations award on trash collection and separation (Vaz, n.d.).

4.4.2 Waste resource management feedback loops: B4 and B5

Issues relating to the waste resource management driver consist of two feedback loops, B4 and B5, as shown in Figure 4.8.

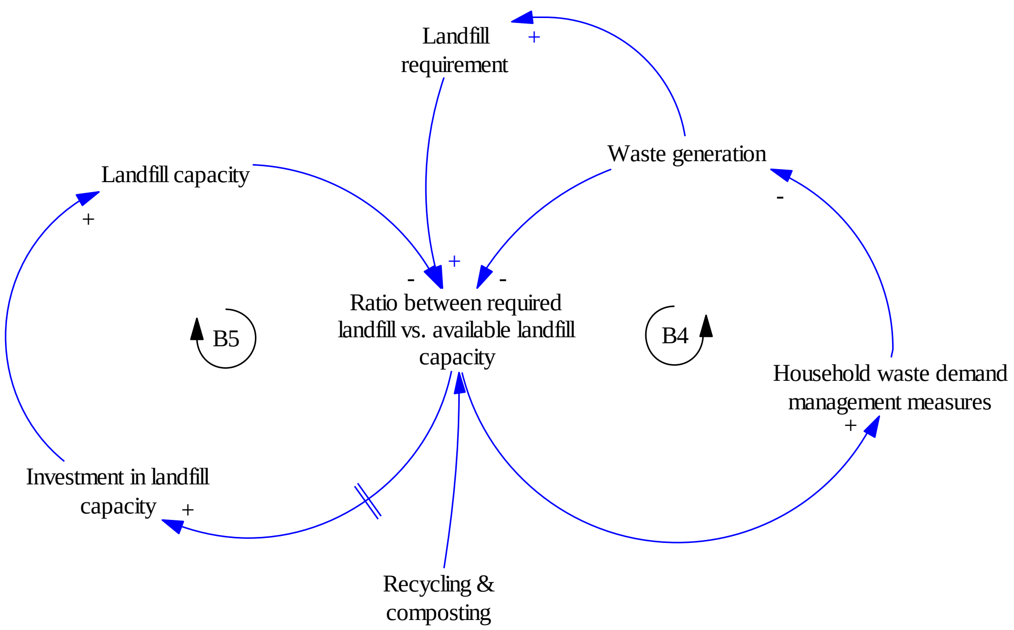


Figure 4.8: Waste resource management feedback loops

The gap between the demand for additional and available landfill capacity is the main variable in the two balancing loops influencing action to waste resource management of domestic waste flows in the City of Cape Town. The need to save landfill capacity was initiated in 2006 with the introduction of the source separation programmes (B4). Identified suburbs were informed and educated to separate recyclables from the remainder of waste generated in households. This resulted in less waste generated and more waste diverted from landfills.

As more recycling efforts are being implemented (B5), such as the new home composting project, a greater increase in available landfill capacity can be expected; however, this is heavily dependent on thousands of households to voluntarily partake in this initiative. The increase in landfill capacity reduces the gap between a demand for more landfill airspace and capacity. It may take longer than expected to meet this demand due to delayed implementation measures by the municipality to increase landfill capacity, as is the case with the pending regional landfill site.

In terms of governance aspect regarding the *degree of user and provider inclusivity in policy formation, planning, implementation and evaluation of these services*, the waste minimisation initiative through recycling supports the current waste management hierarchy, but is limited to selected high-income suburbs only. There is still room for improvement and roll-outs to other areas. However, the city appoints a contractor to collect the source-separated waste in the selected suburbs and recognises that this is an expensive intervention and should not be seen as the only means to divert waste disposal to landfill.

4.4.3 Environmental protection feedback loop: R1

Issues relating to the environmental protection driver consist of one feedback loop (R1) as shown in Figure 4.9.

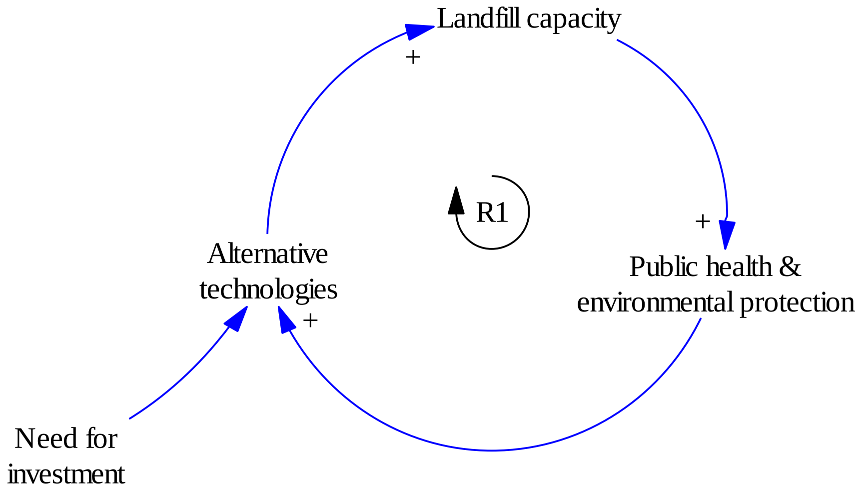


Figure 4.9: Environmental protection feedback loop

Public health in combination with environmental protection is the main variable in this Reinforcing loop (R1) associated with domestic waste flows in the City of Cape Town. The City of Cape Town realised this need in its Integrated Waste Management Plan, 2017–2022, and is looking at alternatives to divert waste from landfills. This will bolster recycling activities, which diverted at least 20% of the total waste in 2015, and will further extend available landfill capacity. This diversion can still be improved substantially through efforts on in terms of the 3Rs throughout the relevant industrial and commercial sectors. This is in line with reaching the long-term goal of sustainability to 'close the loop' by focusing on changing packaging designs, resulting in fewer inputs of materials, as opposed to heavy reliance on quantities of waste recycled. This may be a national government imperative.

The above initiative responds to the governance aspect regarding *institutional coherence*. The municipality has a materials recovery plan, but this may not prove to be *financially sustainable* in terms of the governance aspect, as it is an expensive intervention.

4.4.4 Overall feedback loops on dynamic factors affecting future domestic waste flows

Figure 4.10 illustrates the dynamic factors affecting future domestic waste flows in the City of Cape Town and illustrates how different key variables interact. It shows only one Reinforcing loop (R1), which amplifies change by introducing alternative technologies. The rest of the causal loops are all balancing loops that seek equilibrium.

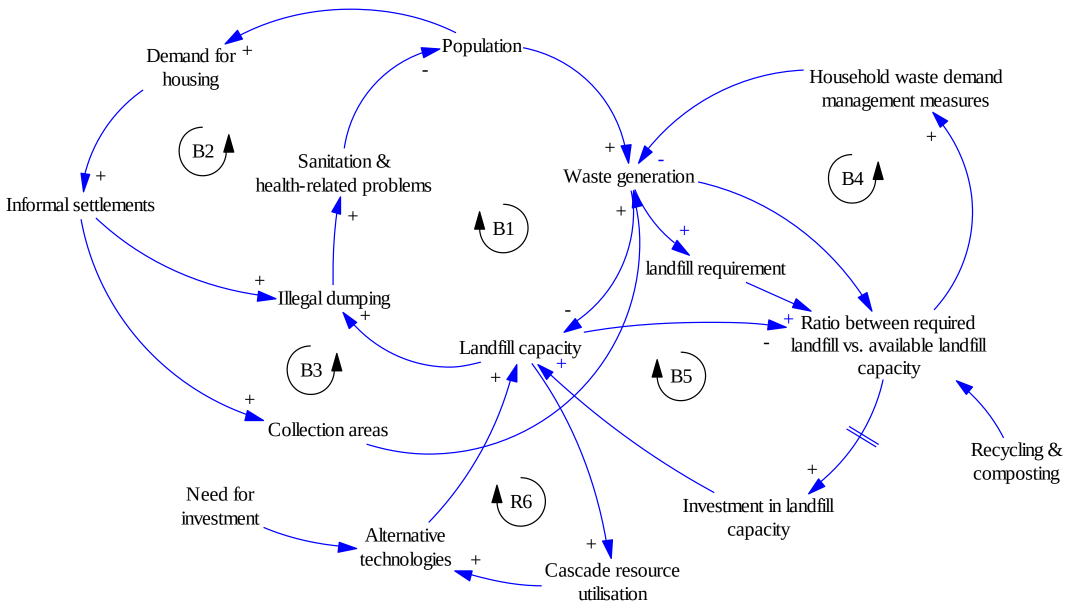


Figure 4.10: Overall feedback loops of the factors affecting future domestic waste flows

4.5 Summary

This chapter presented the results of the study according to the objectives it aimed to achieve. Domestic waste is one output of municipal solid waste disposed of in the City of Cape Town. This study was limited to only examine domestic waste flows in the City of Cape Town. In order to understand the dynamic factors of these flows, a causal loop diagram illustration was used to address the research problem.

Three causal feedback loops were identified, namely i) public health, ii) waste resource management and iii) environmental protection. The main variables in each feedback loop were population, the gap between the demand for additional and available landfill capacity and public health in combination with environmental protection. In summary, an increase in population, as is the case in the City of Cape Town, results in an increase in waste generation, which in turn impacts on available landfill capacity, public health and environmental protection. A combination of current and proposed interventions was identified, such as a change in behavioural problems by residents to combat illegal dumping, the new home composting project, increased recycling initiatives and a pending regional landfill site to carry out the municipality's constitutional mandate to provide basic services to its citizens.

The next chapter discusses the key findings and makes recommendations for future work.

Chapter 5: Conclusions and recommendations

5.1 Introduction

This study presented insights into dynamic factors influencing domestic waste flows in the City of Cape Town in providing additional landfill airspace to the already dwindling available landfill capacity in a developing world context of urban growth.

The objectives of this study were:

1) To examine the drivers of waste flows in the City of Cape Town;
2) To examine existing solid waste management practices in the City of Cape Town; and
3) To explore the dynamic factors influencing future domestic waste flows in the City of Cape Town using causal loop diagrams.

The above objectives were met within the scope of the study by using different methods such as a comprehensive literature review, the use of grey literature and qualitative system dynamics, in particular, causal loop diagrams. Key findings are presented and areas of improvement and recommendations for future work are discussed.

5.2 Key findings from literature review

The literature review revealed that waste generation is inevitable in cities that provide opportunity for economic development and that the types of waste problems are often varied, based on time and the development of societies of various sizes. The magnitude of associated problems, quantities and composition of waste also differs significantly between developed and developing countries and there is no readymade solution for dealing with waste management challenges, as cities have unique landscapes and demonstrate unique needs.

The literature states that waste must be dealt with in a sustainable manner to safeguard the environment for future generations and that a move towards ISWM practices is necessary by ‘closing the loop’ by returning both organic and inorganic waste to beneficial use through recycling. The literature revealed that local governments have little power over consumption patterns by their residents and that focus is mostly on deciding upon the most appropriate waste management technologies and strategies to be implemented. Consumption patterns and waste generation rates vary between developed and developing countries and notably between various income groups. Municipalities are faced with highly significant health and environmental problems and are unable to deal with increasing amounts of waste generated due to lack of funds and knowledge, which places constraints on how to deal with waste effectively.

Three key categories of drivers of waste flows through cities were identified. Economic drivers are consumption patterns, employment and GDP, whereas socio-economic drivers are population and household size. Political drivers were identified as legislation that promotes waste prevention such as the international adopted waste management strategy, which promotes the 3Rs (reduce, reuse, recycle). A well-functioning waste management system needs to respond to these drivers in order for the system to work sustainably over the long term. A framework of three physical systems and three governance aspects to analyse and identify gaps in the system was developed by UNEP to address all aspects of a waste management system. This was discussed in detail in Section 3.4.2 and in Chapter 3.

5.3 Key findings from causal loop diagrams

Key findings from secondary information and causal loops diagrams revealed that there is a positive growth in the population and that it will continue to grow in the future. This study utilised qualitative system dynamics, mainly causal loop diagrams, to provide insight into the dynamic factors influencing future domestic waste flows in the City of Cape Town.

The feedback loops were used qualitatively to portray conceptual models as an aid to think and understand and was based on the ‘two triangles’ analytical framework for solid waste management in the world’s cities, developed for UN-Habitat. It was used to examine the existing trends and realities in the City of Cape Town. This framework has been used widely and shows good work being done on solid waste by cities around the world, including large and small, rich and poor cities. It examined what drives change in solid waste management, how cities find local solutions and what seems to work best under different circumstances (Wilson et al., 2013). The main causal feedback loops were i) public health, ii) waste resource management and iii) environmental protection.

5.3.1 Public health feedback loops

Population growth, increased informal settlements and illegal dumping are the key variables in this feedback loop. Apart from natural births, the population growth is attributed to an influx of people from neighbouring provinces and countries. This implies a demand for more housing and may lead to greater refuse collection areas over longer distances, which impacts on landfill capacity.

The majority of households (47%) fall within the low-income group. Public health is at risk, as illegal dumping remains prevalent in the municipality, despite ongoing remedial measures and stringent by-laws. Illegal dumping costs the City of Cape Town R350 million every year to clean up the waste. Informal dwellings are on the rise, thereby enhancing illegal dumping and impacting on people's health and sanitation. The increase in waste generation reduces available landfill capacity, which has consequences for environmental protection, particularly in terms of solid waste management, air quality and water quality.

5.3.2 Waste resource management feedback loops

Public health in combination with environmental protection is the key variable in this feedback loop. The City of Cape Town has moved towards ISWM with the introduction of the Think Twice separation at source initiative in 2006. It is noted that the number of households participating in the Think Twice separation at source initiative is very low, at 200 086, compared to 1 068 572 households in 2011. However, the municipality does note that funding remains a difficulty to expand this initiative.

Although the city undertook extensive waste characterisation surveys in 2011, further surveys are recommended to assess the changes in the characteristics of the waste where the separation at source waste minimisation scheme has been implemented. The percentage diversion rates through the recycling programmes over the years show time lags between intervention and effects, i.e. the recycling rates significantly improved in 2015/2016 with at least 20,58% of waste by mass diverted from landfill. As this waste minimisation initiative began in 2006, it is only in 2015/16 that the municipality nearly reached Goal 1 of the National Waste Management Strategy of 2011, namely “to divert 25% of recyclables from landfill sites for reuse, recycling or recovery by 2015” and that all metropolitan municipalities have initiated source separation programmes by 2015 (DEA, 2011:23).

It is likely that vehicles collecting the residual waste from the selected Think Twice areas carry less waste than those vehicles collecting normal mixed waste. This should mean huge savings in terms of vehicles and collection costs for the municipality. It has been shown in the literature review (Section 2.3.2) that waste generation rates and recyclable fractions are directly linked to income levels. The higher the income level, the higher the proportion of recyclables in the waste stream. Therefore, the correct recycling initiatives need to be found based on the various income levels across the municipality. The municipality’s mandate is to deliver a refuse collection service to its communities and to meet the objects of the waste management hierarchy.

5.3.3 Environmental protection feedback loop

Public health in combination with environmental protection is the key variable in this feedback loop. The main outcome from this feedback loop is the introduction of alternative technologies to suit the unique environment.

The City of Cape Town realised a need for alternative technologies in its Integrated Waste Management Plan, 2017–2022, and is in the process of investigating alternatives to divert waste from landfills. This will bolster the existing recycling activities, which diverted at least 20% of the total waste in 2015, and will further extend available landfill capacity. Of note is that the municipality does not have control over the consumption patterns of its residents, therefore relevant industrial and commercial sectors are key in ‘closing the loop’ by focusing on changing the packaging designs of goods, which will result in fewer inputs and outputs of materials.

The following section describes the recommendations made based on this study and areas for future research.

5.4 Recommendations

Based on the evaluation, assessment and conclusions of this thesis, further steps are important in managing the waste system in Cape Town.

The City of Cape Town reviews its current waste management system through the ISWM framework. This framework is used globally and provides comprehensive information on physical and governance aspects of current modernisation and sound practices of the municipality through a set of indicators and drivers in relation to each indicator. The current system is presented by guidelines for developing IWM plans, which were set up by the national government in the early 2000s. These guidelines are not as comprehensive as the international framework and, as such, should be extended.

Obtaining detailed information regarding the City of Cape Town was challenging and grey literature was obtained to assist with this study. Recommendation 5.3.1 would greatly assist in achieving this information.

Illegal dumping remains a challenge in the City of Cape Town despite the many efforts in cleaning up the waste to protect public health and the environment. Illegal dumping characterises the ‘personality’ of an area. It would be useful to undertake a study into these hotspot areas in order to understand the dynamics of the settlements, space limitations and needs, collection frequency and the behaviour of residents. Results from such a study may introduce new methods in managing waste to be applied, which may have national significance for municipalities in South Africa.

Further research identified is to turn the feedback loops into a mathematical model for quantitative simulation and optimisation to support policy design, which would fulfil all modelling phases as explained in Section 2.7.

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